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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A study has been made of SXTF requirements in the areas of facility control, computerization, data recording, data links, and facility design. Possible computer/control configuration for the facility are discussed and a strawman design is presented. The advantages and problems to be faced in imposing design standardization are examined. Possible applications of fiber optics in the facility are discussed and evaluated. A detailed survey of the state of the art in wideband

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20. ABSTRACT (Continued)

fiber optic data links and transient waveform digitizers is presented and evaluated in the light of SXTF requirements. Requirements for a spacecraft charging capability are examined.

PREFACE

The contents of this report are based in large part on a series of facility visits and conversations by which we were able to develop a comprehensive picture of how large experimental and test facilities are being designed and instrumented and of the state of the art in the instrumentation as discussed herein. The authors wish to thank the following individuals, facilities, and companies who gave generously of their time to provide valuable information.

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1. EXECUTIVE SUMMARY

IRT has been serving as a resource contractor for DNA providing information for the development of the SXTF instrumentation program plan and conceptual design, concentrating on the areas of facility control, data links (especially fiber optics), data recording and processing, computer architecture, and spacecraft charging.

For this effort we have:

1. Identified possible computer configurations for exercising facility control, data logging and data processing from which a strawman conceptual computer architecture for the facility has been developed.

2. Identified both benefits from and problems to be faced in imposing design standardization on SXTF instrumentation in terms of computers, software, interfaces, signal conditioning, and data links, and reviewed possible schemes for implementing this standardization.

3. Assessed the state of the art in fiber optic data link technology not only in the context of recording SGEMP data, but also in the transmission of data and control signals between the satellite and the facility, in controlling and monitoring pulsed power sources, and as part of a general facility grounding, shielding, high voltage, and dielectric isolation plan.

4. Reviewed the state of the art in the development of transient signal digitizers in the light of SXTF requirements.

5. Defined the source requirements for incorporating a spacecraft charging capability into the facility, assessed the adequacy of existing hardware for providing a reasonable simulation, identified needed development, impact on facility design and costs, and problems created in adding these radiation sources to the facility.

In preparing this report a great deal of data on how large experimental and test facilities are currently being designed and instrumented has been acquired through a series of facility visits to large nuclear physics accelerators (SLAC and LAMPF), laser

and magnetic fusion installations (LASL/ANTARES, L^3/NOVA, GA/DOUBLET), and the LASL Plutonium Reprocessing Laboratory which is summarized in Section 2. For historical interest and comparison, a brief discussion of the way in which CASINO was designed and built is also presented in Section 2.

During the course of our facility visits a pattern emerged which describes the manner in which the rationale for which a facility is built is ultimately translated into hardware. This is discussed in Section 3. The most important points relevant for this phase in the SXTF instrumentation development program in which a conceptual facility design is about to be undertaken are as follows.

Before the production of a detailed hardware design, several steps are required. These include:

1. Production of a system instrumentation block diagram which is a translation of required tasks to be carried out into hardware equivalents.

2. Production of a catalog of needed data/control items organized in a manner which readily translates into a facility design.

3. Carrying out design tradeoffs in which conceptual designs are assessed in terms of factors such as costs, convenience, availability of technology, impact on program schedule, adequacy to achieve planned function, etc.

4. Establishment of a clearly defined set of ground rules under which hardware design is to be carried out, including:

   a. Degree of automation, i.e., hardware or software implementation of tasks.

   b. Specification of facility design practices, standards, interfaces, etc.

   c. Establishment of a facility grounding, shielding, high voltage, and dielectric isolation scheme.

   d. Software specification in terms of language, operating systems, data formats.

These ground rules should be embodied in a facility design practices and standards document. In pursuing the facility design the use of a graphical systems analysis technique such as Structured Analyses for Requirements Definition should be considered. A Standards Committee should be established to enforce conformity of design to the overall facility plan.

In developing this facility standardization in terms of interfaces, signal conditioning techniques, data links, process control hardware, computers, and software will be desirable from the design, operational and maintenance points of view. This process will be complicated because, of necessity, hardware will be purchased from many manufacturers. An attempt to impose standardization at a very detailed level may conflict with a given manufacturers design practices. It may also prove costly because one pays for putting instrumentation in modularized, standard packaging (overdesign). To the greatest degree possible, such standardization should be carried out using industry-wide accepted methods. Commercial hardware should be used and should be compatible with the scheme for standardization chosen to minimize the need to build custom interfaces.

Several possible methods for implementing a standardized design have been examined. If a computer configuration such as that presented in Section 3 is adopted, where all computer hardware is purchased from one manufacturer, it would be logical to use his signal conditioning and interface hardware as much as possible. Otherwise, the choice would be a manufacturer independent scheme such as CAMAC, which seems to be gaining general acceptance for interfacing transducer and process controllers packaged in standard modules to digital computers. In any case, a cost/benefit analysis will determine the degree to which standardization will be imposed on the facility instrumentation.

Various control/computer options are possible, ranging from minimal use of computers for SGEMP and diagnostic data reduction and analysis to complete automation. The scheme which we think deserves careful consideration is an interactive, dynamic, computer-operator system. Both facility operation and data logging would be exercised through a computer network where one or more operators are in the control loop and exercise control through interactive, dynamic graphic displays.

The proposed system is a modular, distributed, multi-task network. At the highest level would be a supervisory computer to which the test directors console and possibly a master control console would be connected. Each major instrumentation system would also have a supervisory processer through which local control could be exercised through a dynamic graphics console. At the lowest level would be a set of microprocessors which would carry out fixed control operations, perform data logging, and do preliminary data formatting.

The advantages of such a system include flexibility, convenience of operation, simplification of controls, enhanced communication between participants, suitability for the test director concept, and ease of maintenance. The disadvantages include added cost for computer hardware and software, additional complexity because extra hardware is introduced into a control/data logging link, and the large effort required in software development.

In Section 4 of this report the applicability of dielectric data links to SXTF are discussed. There are several areas where the use of the links might be attractive. These include:

1. The satellite/AGE interface where dielectric isolation is mandated.
2. Controlling and monitoring the performance of the MBS and PRS where the noise immunity and high voltage isolation provided by dielectric links would be beneficial.
3. In transmitting machine and radiation diagnostics data to the instrumentation screen room.
4. As part of a general grounding and shielding plan based on isolating individual subsystems from each other to minimize noise coupling and ground loops.

The advantages of employing fiber optic links include dielectric isolation, noise immunity, voltage isolation, and subsystem isolation. The disadvantages include added instrumentation complexity, possible lack of suitable commercial units, added cost, and possible radiation sensitivity of the links.

Based on the probable process control and data logging requirements of the facility a set of generic links has been identified. These include:

1. A binary control/data link for monitoring status information (on/off type).
2. A low-frequency analog link for relaying slowly changing data (temperatures or pressures).
3. A digital serial link for transmission of data between computers.
4. A moderately high-frequency link (bw $<$ 20 MHz) for transmission of analog or digital data.

It is possible that not all of these links will be necessary. Versions of each one of these links have either been built for in-house use by some of the facilities which we

visited or are available commercially. Because this is a rapidly developing field, one sh... ...t to see more units become commercially available with a resultant price urop...

Wideband fiber optic links are presently the instruments of choice and transmitting high frequency SGEMP and radiation diagnostic data from the spacecraft to the measurement screen room. However, it is apparent that the two presently existing systems (that from HDL and the one from Lockheed) will not perform satisfactorily in the SXTF radiation environment. We have performed an assessment of the behavior of these links in terms of the required electrical performance in the combined photon and electron environments. Proposed hardening schemes have been examined to see if they will provide adequate performance. Examination was made of the state of the art, including likely near-term technology advances in this area to determine whether a satisfactory system will be available for SXTF. Some alternative schemes for transmitting this data have been identified.

Several important problem areas have been identified:

1. Dynamic Range. Presently employed laser diodes cannot provide a reasonable 40 dB of linearity.

2. Transmitter Hardness. Performance of the transmitter amplifiers employed in present systems will degrade in prompt gamma dose rates above 10^6 to 10^7 rads. This is at least two orders of magnitude lower than required.

3. Fiber Hardness. Presently used fibers do not have sufficient prompt radiation hardness in the photon pulse [10 dB attenuation for 100 rads(Si)] exposure. Moreover, their tolerance to the simulated space electron flux in a spacecraft charging test is inadequate.

4. Size. Both links are relatively large.

Both HDL and Lockheed are working on improvements to their systems. It is likely that problem one will be solved if newly developed laser diodes have the dynamic range claimed. It seems likely that problem two can be solved by shielding, but only at a cost of increasing the size of these units. It is possible that by clever design, transmitter amplifier electronics can be made to operate at a higher radiation level. However, it is not known whether such design techniques are presently being applied to either system. It is likely that the prompt radiation tolerance of fibers should be sufficiently improved, but this is an area which should be watched. The effect of high

energy electrons impinging on the cables can be minimized by shielding them with a sufficient thickness of dielectric.

Of the presently identified alternate means of driving fiber optic links, LED's are the most promising. Their performance and operating requirements are superior to laser diodes in all respects except bandwidth. Units have been produced in reasonably small packages with 150 MHz bandwidth, which is adequate for radiation diagnostics but inadequate for SGEMP data. It is possible that improvements in diode technology coupled with experimentation in driving circuitry may yield instruments with adequate bandwidth. Other systems based on GaP acousto-optic modulators or Fabry-Perot resonators may become viable candidates.

Equally important as the ability to transmit high frequency SGEMP and diagnostic data is the requirement to record it digitally for analysis. At present the Tektronix R7912 is the only available instrument for direct digitization of high frequency (>100 MHz) data. While adequate in terms of performance, its high cost (~20K per unit) limits the number of channels that the facility can provide. This has an impact on the way measurements are carried out. Less information than might be desired in areas such as source diagnostics or SGEMP data may be provided because of cost limitations on the number of high frequency data channels provided. However, there is active development going on, primarily in the laser fusion and weapon diagnostics community, to provide all solid-state alternatives based on peristaltic analog shift registers built from CCD's. Prototype units have already been built for Sandia and L^3 which have reported bandwidths up to 250 MHz. If the technology is perfected in the next couple of years, these units will offer attractive alternatives to R7912's and will probably be cheaper by at least a factor of two or more, smaller, and consume less power. This is a technology area which should be closely watched. Prototype units should be acquired when available for evaluation. In addition, there is the possibility that digitizers with reduced bandwidths (20 MHz or less) based on other solid-state technology will be available at a cost of a few hundred dollars per chip.

In Section 5 the problem of incorporating a spacecraft charging simulation into SXTF has been examined from the points of view of required hardware, adequacy of existing technology and problems associated with the introduction of electron beams into the test chamber. It is reasonable to incorporate this capability into SXTF for at least three reasons:

1. A spacecraft charging survivability spec may be levied on Air Force satellites. Since the responses of spacecraft structures and electronics to

electron-induced discharges are similar to that associated with SGEMP, it seems logical to carry out integrated system survivaiblity tests for ESD in SXTF which will be well instrumented to study this phenomenon.

2. Evidence exists that the SGEMP response of model satellites can be enhanced if precharged. It may be that a reasonable SGEMP survivability test should include precharging.

3. Total dose problems in materials or electronics due to high energy, nuclear space electrons can be studied on operational spacecraft in SXTF.

As a minimum it seems reasonable to provide the following sources:

1. Low energy electrons (E <30 keV).

2. High energy electrons (E <4 MeV).

3. UV, at one sun (AMO).

Whether refinements such as a reasonable simulation of the electron spectra or inclusion of ions are needed is still to be determined.

Inclusion of item 1 is relatively easy. Several candidate sources exist. Introduction of item 2 is possible but the impact on facility design and cost will be significant. Sources of electrons of this energy (accelerators) cost several hundred thousand dollars each and several may be needed for uniform coverage over a spacecraft-sized area. The problem and cost of introduction (support structures, penetration, shielding, power, controls, monitoring devices) are substantial and will have to be factored into tank design. A solar simulation capability is likely to be provided to exercise the solar cell panels during SGEMP testing.

If electron sources are introduced into the tank, problems will be encountered because of dielectric charging of insulating surfaces, dose and dose rate problems caused by the high energy electron component penetrating electronics, and from the hard x-rays produced by these electrons, as well as from RF noise generated by the sources. Some of this can be minimized by properly collimating the electron beams.

2. DESIGN OF OTHER FACILITIES

2.1 FACILITY VISITS

One of the tasks which IRT undertook in providing this material to be used in the preparation of an SXTF Instrumentation Plan was a survey of how the design, construction, and operation of large experimental and test facilities is being carried out. This was done for several reasons.

1. To ascertain what is the state of the art in instrumentation areas of relevance to perceived SXTF requirements, including dielectric data links, transient waveform digitizers, computer architecture, x-ray diagnostic instrumentation and facility control schemes.

2. To identify novel schemes for noise reduction, shielding, high voltage and dielectric isolation, and for the solution of other problems to be faced in designing SXTF which may have been developed at other facilities facing similar tasks in a different context.

3. To identify the relative costs of facility instrumentation and software as well as development times in order to establish some rules of thumb for carrying out cost-benefit tradeoffs in the SXTF instrumentation design.

4. To search for developed and applied system analyses techniques by which one can translate the purposes for which a facility is built (the Why) into a set of functional specifications (the How), and then into hardware (the What).

5. To ascertain what kind of and how measurements are taken by spacecraft manufacturers in carrying out system qualification testing, and to learn how these measurements will have to be modified, and what special instrumentation will have to be provided in carrying out SGEMP testing in SXTF.

This survey has been carried out primarily through a series of visits to large experimental and test facilities in which the need to control and record large numbers of parameters in a real time setting often in environments with features (noise, pulsed

power sources, etc.) similar to those of SXTF might be found. The kinds of facilities visited included large nuclear physics accelerators, laser and magnetic fusion installations, spacecraft manufacturers, and a large plutonium reprocessing laboratory. We present a brief description of some of the significant features for each of these facilities to identify points of interest. A more detailed description is contained in a set of trip reports.

2.1.1 Linear Accelerators

1. Stanford Linear Accelerator (SLAC). This is the world's largest electron Linac (two miles long 22 GeV). It was developed between 1962 and 1966 at a cost of $120M. The present operating budget is $30M. The accelerator is organized into a total of 32 modular sectors comprising the injector, 30 sectors each containing eight klystrons and waveguides and one sector comprising the beam switch yard. A typical sector involves the monitoring of 20 analog quantities, 120 status quantities, and exercising 40 to 50 control functions. Status quantities monitored include those typical of power supplies, condition of vacuum pumps and magnets. Analog quantities monitored include magnet currents, power supply voltages, and klystron frequencies. Control functions include programming power supplies, operating vacuum valve controls, switching in and out ac substation power, cooling pumps, and klystrons. Thus, facility operation means keeping track of a total of 4,000 status, 650 analog inputs, and 14,000 control functions. From the standpoint of facility control it is a relatively old facility which is currently being upgraded.

Because of the large number of parameters to be monitored and the modular nature of the facility, a control scheme was developed based on a computer network which consists of a main computer and a set of smaller minicomputers, each one monitoring several sectors. The computer control scheme is currently being revised to one more in line with current practice. Three supervisory minicomputers (DEC 11/34) will be interfaced to a group of front-end microprocessors (Motorola 6800), for local task execution, data monitoring, and initial data processing. Overall facility control is exercised by three operators through a series of computer-interfaced touch panels (Ref 1). Most facility instrumentation has been developed in-house primarily because SLAC has a large instrumentation group which must be kept busy. On the other hand, the users, i.e., experimenters rely more on commercial instrumentation, much of which is CAMAC based.

2. <u>Los Alamos Meson Physics Facility (LAMPF).</u> This is a large 800-MeV proton Linac used for nuclear physics experiments and as an intense neutron source for various applications, including nuclear weapons diagnostics. The facility was designed in 1964 through 1966 and built in 1966 through 1972 at a cost of approximately $55M, of which approximately $8M was devoted to instrumentation and software. The structure of the facility is modular, organized in the same fashion as SLAC (Ref 2).

At present the system is controlled with a fairly large computer (SEL-840), which has the capability of handling 60 tasks at once. The computer is connected to 80 modular data and control stations through a remote interface unit which is a parallel unit capable of talking to all the modular control stations simultaneously. Each of the modular control stations has a set of local controls and analog data displays. These stations control and monitor RF power, vacuum, steering magnets, klystrons, water supply, etc. Each station is responsible for approximately 125 data and control items, broken down into 50 analog, 12 status set points, 50 status monitoring points, and 13 relay controls. There are a total of 10,649 items to be monitored and controlled. Overall facility control is exercised by a single operator through a set of touch panels, which interface with the main computer. This system is operated in a dynamic, interactive mode, i.e., one in which many functions are performed automatically while critical operations are carried out by the operator.

A new computer system is being developed to replace the 840. It will be built around a DEC VAX 11/780, plus several 11/34's. The original control system was built in-house. However, the system designers said that if they were to do it all over again, they would use some standard scheme based on CAMAC or IEEE Interface Bus. In fact, a new control console is being designed based on the latter.

In the design of this facility it was decided early on that it would be important to clearly specify facility instrumentation and design practices down to the individual sensor and transducer level. To this end a Standards Committee was set up to monitor design. The standards were written into the specs imposed on outside vendors, taking into account as much as possible accepted industry practices. Another interesting feature of this facility is that two p[illegible] systems are provided to minimize noise coupling into instrumentation. One is a clean, carefully grounded and shielded system for computer and control functions. The second is a dirty system used to provide power for tasks such as pumps and motor operations.

2.1.2 Fusion Installations

1. Los Alamos ANTARES Laser Fusion Installation. The ANTARES facility, which is under construction, will be a six amplifier, 72 beam, CO_2 laser fusion facility. Its design spec is that it will produce 100 kJ of energy in a pulse 0.25 nsec wide with a power output of 200 TW. It is designed to reach break even, i.e., the fusion energy out will be equal to or greater than the laser energy input. The projected cost is $55M of which control instrumentation and software would represent $6M. Organization of the facility is described in Reference 3. There is an isolated control room which will contain the supervisory minicomputer as well as a set of dynamic-graphics control consoles. A laser hall will contain the pulsed power system and laser amplifiers and the various laser beams are brought to focus on the target in a target building.

This facility will use a distributed multiprocessor system in which overall facility control is exercised by a supervisory minicomputer. Each of the major facility subsystems communicates with the supervisory minicomputer through a communications microprocessor. The latter in turn controls a series of front-end microprocessors (FEPs) which perform specific control functions, such as driving stepping motors, data monitoring and preliminary data formatting. The supervisory minicomputer is an HP3000 while the microprocessors are Motorola 6800's.

A novel feature in the proposed facility design is that it makes extensive use of fiber optic data links. This was done as part of an overall grounding, shielding, and high voltage isolation scheme (Refs 4,5) to minimize noise coupling from the set of twenty-four 1.1 MeV MARX generators which create pulsed electron beams to drive the laser amplifiers. Each of the major facility subsystems is isolated from the others. Communication between front-end microprocessors, subsystems communications microprocessors, and the supervisory minicomputer are affected through serial fiber optic data links. In addition, most of the connections between individual data sensors or control instrumentation and FEPs are also made through fiber optic data links. A generic set of these links has been designed to carry out both analog and digital control functions, monitoring status, low frequency and moderately high frequency analog ($\sim$10 MHz) data recording as well as to provide timing and firing triggers.

Facility timing is generated by the supervisory computer clock and timing signals are transmitted down fiber optic systems which provide signals with rise times of the order of 5 nanoseconds. Although many pulsed power sources must be fired in a carefully timed sequence in this facility, timing is not as critical as will be required for SXTF. The pulsewidths of the electron teams are several microseconds and critical

timing for injection of the laser pulse must occur in a window which is about 100 nanoseconds wide. However, the design of this facility represents a novel approach to minimizing noise coupling in an electrically noisy facility, while providing dielectric isolation between subsystems. Another interesting fact is that facility instrumentation design has been carried out through a system analysis technique called Structured Analysis, which is a graphics-based methodology for specifying and organizing systems requirements (Refs 6,7). It is recommended that the applicability of the system design techniques used here be studied carefully for their applicability to SXTF.

2. Lawrence Livermore Laboratory SHIVA Laser Fusion Installation. The SHIVA facility is a 20-beam neodynium glass system which has just become operational. Total cost was $25M. The system is designed to produce 10 kJ output in a period of 0.1 to 1 nsec yielding a peak power of 20 to 30 TW (about 1 percent of breakeven). It is one of a series which will culminate in the NOVA facility, a 200 to 300 kJ, 200 to 300 TW, 1 nanosecond pulsewidth system which will yield breakeven. The facility is organized into four major components (Ref 8): a power conditioning system which is comprised of a bank of 20 keV power supplies, high-energy storage capacitors which are used to pump the laser amplifiers, as well as instrumentation for the timing, controlling, monitoring, and firing; an alignment control system used to align the various optical systems through which the laser beams pass; a laser beam diagnostic system for monitoring beam throughput and output; and the target diagnostic system.

As with all of the other major facilities examined, instrumental control is exercised through a distributed multi-processor network. Front-end control and data tasks are carried out through a set of FEP's which are DEC LSI-11's. Functions handled include:

1. Transformation of high level commands from intermediate level processors and regeneration of them in the output format required to drive hardware.
2. Collection of raw data, reducing and compacting it, and transmitting it to the intermediate computer.
3. Taking care of interlocks and interactions between the FEP's.

The kinds of functions which are controlled include:

1. Driving of the approximately 1000 stepping motors which are used to align and monitor the portion of the laser beams.

2. Timing, charging, and firing 10^3 flash lamps from a bank of 8000 20 kV capacitors.

3. Monitoring the laser beam performance which is done with a set of 120 photodiodes and 60 calorimeters.

Each of the four major subsystems is controlled by a second-level processor, which is a DEC 11/34. The functions of the second-level processors are to:

1. Supervise the operation of the FEP's

2. Handle interface interlocks between FEP's

3. Permit direct operator intervention in each system, i.e., to operate each system independently.

4. Record all parameters for diagnosis and analysis

5. Provide a quick-look data analysis for each shot

6. Provide functional diagnosis.

At the top of the hiearchy is a third-level supervisory processor which is a DEC 11/70. It has the following functions:

1. Provide overall facility control through a console with a series of touch panels.

2. Provide archival storage of diagnostic data

3. Control interfaces between the main and second level computers and I/O devices for program development.

Most target diagnostic data is performed on a large computer which is off-site.

Several fiber optic links have been used to transmit data in some of the subsystems, but not as consistently or extensively as in ANTARES.

High voltage isolation between the control room and power conditioning system is effected through 50 to 60 kilovolt optical isolators.

Some comments about the computer system can be made which are relevant to SXTF. Each subsystem has been developed so that it can be operated independently of the others. This is done for two reasons. First, there is a need for redundant facility control. Second, during the development of a complicated system containing several major subsystems it is necessary to have independent control so that they can be brought up independently of the others. Having diagnostic information stored on higher

level processors is applicable to SXTF where both a quick-look capability and the need for rapid analysis of anomalies may be required. The bulk of the data can be stored in an off-line computer for archival purposes, and retrieved as needed. Major data analyses in this facility is done off-line on a large computer system.

Another point of interest is that many of the diagnostic techniques used for target analyses are similar to those employed in diagnosing the performance of the flash x-rays and SGEMP response in SXTF. Major x-ray diagnostics are done with streak and pin hole cameras, calorimeters and x-ray diodes. A major problem in looking at the response of the output of the fusion device is the short times over which energy is generated, which are typically less than a nanosecond. The laser fusion groups, especially Livermore, are quite active in developing novel schemes for radiation diagnostics. In particular, they have been developing digital recording devices based on new solid-state technology to replace conventional transients digitizers and photographic film. Some of this work is discussed in section 4.4 of this report.

2.1.3 Spacecraft Manufacturers

Three satellite manufacturers were visited as part of IRT's facility survey. These were TRW, Ford Aerospace, and Hughes. Our aims were to learn (1) what integrated system tests are typically performed on spacecraft, (2) how they are performed, and (3) what are the requirements for commanding the spacecraft and monitoring its behavior during these tests. It is important to assess the impact of these issues on SXTF instrumentation in terms of provision of needed but specialized hardware, such as data links and interface electronics required for the necessary interaction with the rest of the facility control and data monitoring network. In this report we have concentrated on possible schemes and problems in bringing out satellite data, while maintaining dielectric isolation during testing. This information is discussed in section 4.2.2.1.

During the course of our discussion with the spacecraft test groups, several key issues were raised which we would like to see answered and which are hopefully being addressed by TRW and others. These include:

1. Does dielectric isolation need to be maintained? The discussion presented in section 4.2.2.1 is predicated on that assumption. Inductively loaded cables may decouple the response of the spacecraft during the x-ray tests. Such a scheme would not provide needed dielectric isolation if spacecraft charging

tests are also carried out where the spacecraft may become charged to relatively high potentials in relation to the tank. If the need for dielectric isolation is not necessary, then instrumenting spacecraft might be done using normal procedures with inductive decoupling.

2. What are the minimum number of parameters needed to monitor the health and performance of the spacecraft in the tank? Presumably thermal cycling will not be part of an SXTF test (although it may be if the facility is used for other integrated system testing). There was some disagreement between the different groups with whom we talked as to whether one needs all of the extra housekeeping sensors which are installed for other kinds of qualification testing, provided that the stability of the spacecraft in the SXTF is tested before SGEMP tests are begun.

3. The kinds of test proposed for SXTF represent a more complete integrated system test than any usually carried out. For example, much of the testing of payloads is not carried out during a thermal vacuum test. The performance of the antennas in a communications satellite are typically carried out in an anaechoic chamber to measure power output and on a test range whose dimensions are such that a far-field pattern of an antenna can be measured. There was some controversy between the test engineers with whom we spoke as to whether one could adequately monitor the performance of antennas in a thermal vacuum tank. In addition, solar cell panels are not usually tested during other integrated system tests in a thermal vacuum tank. This is especially true for three-axis stabilized spacecraft. The consensus of the engineers with whom we talked was that it would be difficult to maintain the thermal balance of the spacecraft in a thermal vacuum tank for a one-sun solar illumination. There was relatively little definition as to how the sensors of the surveillance satellites are tested. We would like to see more discussion of this problem.

4. There may be conflicts between the need to maintain a controlled environment to preserve the health of the spacecraft in the tank and the need to establish a specific environment for SGEMP tests; i.e., will the placement of cold walls and heaters to provide a dynamic thermal balance conflict with the placement of dampers and backscatter grids to maintain spacecraft isolation.

5. There may be some difficulty in sensor placement. If the qual model spacecraft is a flight spare then one must be careful about making modifications to incorporate SGEMP and other diagnostic sensors. If provision is made for their incorporation in advance how will this impact the later performance of the spacecraft. Will one remove these sensors after testing which may alter the internal structure, weight balance, and thermal behavior of the satellite? In particular, if dielectric isolation of the spacecraft is maintained through the use of fiber optic links, then provision has to be made for mounting transmitters and any multiplexing equipment which interface to spacecraft sensors. In addition, current generation, hardened spacecraft depend upon a Faraday cage to provide electromagnetic shielding of electronics. In placing diagnostic instrumentation on and in the spacecraft one will have to be careful to maintain the integrity of the Faraday cage.

6. It must be determined what special instrumentation the facility will be required to provide and what will be provided by the manufacturer. Of particular concern is who will provide dielectric data links and interface electronics if required. Another question to be answered is whether there is any other special hardware not normally used in integrated system testing which will be needed for an SXTF test.

2.1.4 LASL Plutonium Reprocessing Facility

The LASL Plutonium Reprocessing Facility was visited because it contains a sophisticated computer-based process control system. This facility was built over a period of three years at a cost of $75M. Computer hardware costs were approximately $1M, while a similar amount was spent on software. Because of its nature, there are requirements for high reliability in operation while maintaining a controlled environment and tight security.

Material reprocessing is done manually in a series of hot labs in the center of the building. The overall facility environment is controlled by a sophisticated computer-based system which has essentially four tasks. It controls heating and ventilation. Like a spacecraft assembly clean room, this facility uses differential pressure to control the environment, although in a different manner. In a facility such as SXTF one wishes to maintain the pressure inside the chamber when not under vacuum above ambient to keep

contamination out. In the Plutonium Facility the pressure level increases as one goes toward the outside of the building in order to keep contamination in. The remaining tasks controlled by the computer system are fire detection, radiation monitoring, and alarms. Because of the need for reliability there is a second backup computer which can be switched into control facility operation, which in addition can also be done manually.

The development of the computer software to run this facility was a 14 to 15 manyear effort and based on two commercial packages. One was obtained from Rockwell and was originally designed for power station control. A second package was obtained from Honeywell for facility control. Status monitoring and process control are exercised through a series of high resolution, four color displays with a keyboard and cursor system for exercising control and data interrogation. There are two displays in each console, one for fans and power and the second for heating and ventilation. When an alarm is triggered a flashing message in red is activated. In addition, a fault location diagram is placed on the screen. A backup teletype prints out the alarm. A special feature of this control system is that the status of the facility can be examined through a series of functional diagrams. One can call up the flow diagrams for different portions of the facility which show how pieces of equipment are connected together. This is not a straight linear instrumentation diagram as one sees incorporated on the panels of vacuum systems, for example, but is somewhat condensed, showing both the functional relationship of the elements portrayed and the status of different control points. Systems such as this one are probably more complicated than is needed for facility environment control at SXTF. However, it is a good example of to what degree facility control can be simplified by computerization and development of extensive software packages. If it is decided that SXTF will have a fairly sophisticated computer network for exercising facility control, then the possibility of obtaining commercial packages for controlling elements of the facility environment such as heating and air conditioning should be examined.

2.2 CASINO FACILITY

("How Its Been Done in the Past")

CASINO represents one of the most recently developed large flash x-ray facilities. Many of the types of instrumentation to be included in SXTF are very similar to those installed in CASINO. SXTF is a much more complicated facility in terms of sheer

numbers of instruments, the presence of a sophisticated environmental chamber, and the need for simulating an isolated space environment which restrict the solutions to obtaining environmental and instrumental data possible. However, this facility represents the state of the art in x-ray test facilities. Therefore, for historical comparison we have included this brief section on the development of the CASINO facility.

CASINO has four water lines, two Marx generators, drift tubes, and an x-ray converter. The x-ray source and associated controls were designed and fabricated by Maxwell Laboratories. The remainder of the facility design was provided by an architect and engineering firm. IRT was responsible for the design of the machine diagnostic instrumentation. This effort was coordinated with Maxwell who specified what was needed for diagnosing the behavior of the system. The Naval Research Lab (NRL) and the Naval Surface Weapons Center (NSWC) provided input in defining machine diagnostics from an acceptance and maintenance standpoint. NRL was the technical advisor to NSWC and had the task of deciding whether the machine was operating according to acceptance specifications. NSWC was the facility operator and had to perform maintenance to keep it operating according to specification. As a result all of these parties were concerned and had input as to how diagnostics were to be conducted.

NSWC and IRT were the primary participants in decisions about hardware and standardization. A major element in the CASINO instrumentation design was the use of the then newly developed Tektronix R7912 transient digitizers. A maximum effort was made by Tektronix to deliver some of the first production units to IRT for checkout prior to shipment to NSWC. As these were a novel technology, both Maxwell and NRL were also involved because of their interest in reliability and believability of data recorded on a device other than an oscilloscope. As finally configured, the system contained twelve waveform digitizers, one for each diode voltage and current, one for each pulse line, and for the photodiode which served as a radiation monitor and one spare. One could instrument the facility diagnostics in this manner because of the limited number of channels required. Clearly such a scheme is not feasible on a cost basis for SXTF.

After the decision was made to use the waveform digitizer, many other elements in the instrumentation plan fell into place. At that time Tektronix provided an interface between the R7912 and the DEC PDP-11 computer. This determined the choice of a computer. A configuration was chosen based on a PDP-11/40 computer with

24K of core, two moving head disks, two tape recorders (one each seven and nine track), a printer, plotter, paper tape, a Tektronix display and entry keyboard with a hardcopy unit, plus other options associated with the performance of the central processor. Having chosen a DEC computer it was logical to employ a multiplexer and analog-to-digital converter (ADC) manufactured by the same company. The multiplexer has 64 channels and the ADC is a 12-bit unit, 11 bits plus the sign bit. The system had a number of general purpose input-output, parallel 16-bit words for control functions. This was a standard product of DEC. Thus the degree of computerization was limited to diagnostic data acquisition and standardized on DEC equipment and links primarily because that was what the R7912's required. There was no intention of developing a top-down, computerized facility control and data monitoring scheme.

The facility instrumentation plan was contained in an instrumentation report prepared by the A&E. For this IRT developed instrumentation and equipment lists that were submitted to NSWC for purchasing. NSWC would then factor their requirements into the list and coordinate with IRT. There was daily communication between IRT, Maxwell, and NSWC during the design, construction and checkout of the facility. A point to be noted here is that the facility was developed and built by a relatively small group of participants, primarily Maxwell for the photon source, IRT for diagnostic instrumentation and other details on the internal structure of the facility, NSWC for user instrumentation which was copied to a large degree from that developed by IRT for diagnostics, and a facility contractor. As planned, there will be many more participants in SXTF design, development, and construction. Therefore, the need for a well documented design with a great deal of thought devoted to interfaces as well as close overall coordination is mandated.

The A&E instrumentation report described the structure of the test area, which has concrete block walls for radiation shielding and metal cladding for RF suppression, the test area doors, the grounding system, the shield room specifications, the equipment layout in the diagnostic room, the motor generator, the isolation transformers, drawings showing installations specifications, types of cables, lengths of cable, radiation safety calculations, test cell ceiling specifications, interconnections between rooms, and the type and location of connector panels by which cabling is brought into the shield rooms. It is recommended that a copy of this report be obtained by the facility designers for reference.

The user data room was designed and constructed using the specifications generated by IRT for the diagnostic data room. The instrumentation system was similar

and had eight waveform digitizers, additional memory, analog tape recorders, a 192 channel Vidar multiplexer system for low-frequency data. Thus, the total number of waveform digitizers for fast data provided for the facility was twenty.

The machine diagnostic computer was used to control the waveform digitizers and acquire and process dosimetry data. Dosimetry was primarily calorimetric measurements taken with 0.001 inch thick gold foil calorimeters and pulse shape information using a scintillator coupled to a photodiode. The first step prior to a shot was to initialize all systems. The waveform digitizers needed to be read for background, switch positions, status, and then reset prior to the shot. Baseline data from the calorimetry multiplexer and ADC was read and stored. After all the initialization was complete and the system had responsed in a positive manner, the computer issued a command to the control room to proceed with the shot.

After the flash x-ray was fired, the computer was triggered to acquire diagnostic data which was processed to be displayed and output on the hardcopy unit. Initially the time required to read and process such data was approximately forty minutes. This relatively long period was a function of the amount of data required and the nature of the computer software for processing. Total processing time was reduced by approximately one-half through modifications to computer software. With twelve waveform digitizers and a 64-channel multiplexer, the amount of processing time was large, even with optimization because of the huge amount of data that was generated. One of the factors which increased processing time for facility diagnostics was that the use of R7912's encouraged the production of more diagnostic information than was usually needed. Thus, the vast majority of all the printout was never examined. There is a strong incentive therefore for the diagnosticians to develop integral means of diagnostics. The speed of computers has not increased significantly since CASINO was built. To copy the CASINO diagnostics scheme, one will have to go to a very large computer to handle the amount of diagnostic data processing required for SXTF. More likely one will use a series of front-end microprocessors for acquiring and processing SXTF diagnostics. A reasonable control scheme for SXTF, discussed in Section 3, will employ one or more of these front-end processors to control and monitor each MBS module plus one or more for the PRS tied to a central minicomputer.

The present configuration of CASINO has changed considerably since the original installation. The changes that were made resulted from the reduced demand for diagnostic instrumentation on a day-to-day basis once the behavior of the sources was characterized. The low frequency analog data acquisition equipment is no longer in a

diagnostic room. Most of the users of CASINO have not had requirements for fast data channels. They use scopes for mid-range data and the low frequency system for most other data. This will not be true for SXTF.

The waveform digitizers used in CASINO were a new design and had many of the problems associated with new equipment. Maintenance by Tektronix was good, but there was a continued recycling of instruments to the repair facility. However, given the large number of digitizers available in the facility that there were always enough to do diagnostics. There is a warning here. If one uses a new technology item one should leave a sufficiently long time to debug it. While it is reasonable to delay instrumentation choices to take advantage of the state of the art, one must make choices early enough to ensure operational reliability when the facility comes on-line.

3. SXTF FACILITY ARCHITECTURE

3.1 INTRODUCTION

One of the purposes for which the facilities tour was undertaken was to examine the manner in which large test installations are planned, designed, and constructed. From these visits a pattern emerged which also seems to fit the manner in which the SXTF program is being carried out. In this section we first briefly discuss the steps which must be taken in proceeding from the starting point when the need for a facility such as SXTF becomes apparent to the time it comes on-line. We emphasize those features of the development process which are relevant to the functional and conceptual facility design now going on, as well as pointing out some specific steps which should be taken to ensure a successful design.

Based on current facility design practice and the probable functional design of SXTF, we present a Strawman conceptual computer design which represents a logical translation of the former. This design takes into account that SXTF will be a relatively complicated facility if compared to CASINO and other current radiation test facilities. There will be a need to simultaneously control and monitor several complicated systems including the tank environment, timing and firing the MBS and PRS, recording and processing numerous channels of diagnostics and SGEMP data, and interfacing with the AGE/Satellite System. The principal feature of this design is its extensive use of front-end microprocessors (FEP) to perform specific facility control tasks, data logging, and data formatting. The availability of relatively inexpensive microprocessors has revolutionized facility design since CASINO was constructed. Previously enunciated computer schemes (Refs 9,10) do not adequately take this into account. The applicability of microprocessors to SXTF is discussed below. Whether the proposed scheme is the most reasonable for facility design will depend on all of the cost-benefit analyses which are still to be performed which must take into account a variety of parameters listed in the text.

A facility such as SXTF will require performance of many kinds of similar tasks which lend themselves to standardization and computerization. Application of

standards will make the facility considerably easier to design, operate, and maintain. In recognition of this fact a set of commonly used instrumentation standards has been developed. The applicability of and problems involved in standardization of the SXTF design will be discussed. One of the tasks to be performed before carrying out a translation of facility requirements into a hardware design is a detailed analysis of data and control requirements carried out according to a scheme which aids in the design process, especially in seeking out areas of commonality to which standardized methods of hardware implementation may be applied.

Given the incorporation of computer control and data processing in instrumentation systems, new techniques have been developed which permit the operation of complicated systems by a relatively few or even a single operator. These systems are computer based, dynamic graphic schemes in which only those control operations and parameters of immediate interest are placed in the foreground, while routine or unimportant items are carried out under computer control. A brief review of these systems is presented. An important point is that with them it is easy to provide a test directors console as well as communication between different participants in an SXTF test.

3.2 FACILITY DESIGN PROCESS

The design and construction of large facilities typically involves several groups of participants, each one of whom brings different points of view to the program, because of their role in it. These include:

1. The customer: in this case DNA, who has commissioned the facility because of a perceived need to be met under its charter.
2. Analysts: participants commissioned to provide specific assessments and technical information required to carry out the design, development, and testing cycle.
3. The program manager: responsible for seeing that the participants carry out the program plan.
4. Designers: responsible for preparing a program plan, functional designs, hardware designs, test procedures, etc.
5. The constructors: translate the program plan into hardware, facilities, and software.

6. The facility operator (and usually maintainer).

7. The reviewers: assess the program in the light of objectives (why the facility is built), adequacy of functional design to meet objectives, adequacy of hardware to carry out identified functions, and conformity of the program to plan.

8. The users: in this case the spacecraft manufacturer, SAMSO, as well as the SGEMP technology community.

Of course, an individual group may perform one or more of these functions for particular areas. In order to produce a facility which meets the requirements of the customer in a cost-effective and timely manner all of the participants must understand the program requirements and their relative priorities. In addition, there must be frequent technical interchanges between participants as well as detailed documentation of significant program milestones.

Generally the path from conception to operation is best carried out in a series of steps which are part of a top-down design, i.e., one which proceeds from purposes to a detailed hardware design. These include:

1. Definition of the facility purpose. Specification of the reasons why the facility is being built are needed to establish standards which must be satisfied during detailed facility design. Generally the choice as to what is included in the facility must be assessed in the light of the facility rationale as well as on criteria such as cost, convenience, etc.

2. Preparation of functional specifications. In order to carry out the functions for which the facility is being built, a set of data requirements and the corresponding tasks and operations to obtain them will be defined which leads to a facility functional design. For example, Figure 2 in Reference 10 is a prototype functional design. At this stage of the design process one begins to make decisions as to whether a particular item is mandatory, desirable, or a luxury. Making these decisions is one of the most important tasks for the reviewers who must keep (1) uppermost. It is at this stage that we recommend the use of some graphical systems analyses techniques such as Structured Analyses for Requirements Definition (Refs 7,8) in order to produce a clearly defined and complete set of specifications.

3. Production of a system instrumentation block diagram. This is generally a translation of the functional design into a hardware implementation specified in general terms. These elements, in turn, will be further broken down as the instrumentation design is developed. Figure 3 of Reference 10 is an example at a relatively coarse level of specification, while Figure 2 (Ref 9), is a case of a more detailed breakdown. In this process several steps are required.

   a. Production of a catalog of needed data/control items as to type, numbers, frequency characteristics, manner of transmitting or controlling, how recorded, importance in the facility operational scheme, how often scanned, organized in a manner which readily translates into a facility design.

   b. Carrying out design tradeoffs in which the proposed design is assessed in terms of suitability to achieve desired goal, cost, convenience of operation, state of the art, conformance to standard manufacturing practice and overall facility design philosophy, availability, impact on program schedules, considered from a variety of viewpoints: technical, economic, operational, and political.

4. Establishment of a clearly defined set of ground rules under which detailed hardware design is to be carried out. These include decisions on:

   a. The degree of automation, i.e., hardware versus software in the implementation of specific tasks.

   b. Specification of facility design practices, standards, and interfaces for exercising control and data logging, and required signal conditioning; whether to adopt industry and manufacturing standards like CAMAC or IEEE Interface Bus, and the level to which standardization will be imposed. This is discussed in more detail in section 3.5.

   c. The nature of data links chosen will depend on the degree of computerization, and whether and where fiber optic systems are incorporated.

   d. Establishment of the facility grounding, shielding, high voltage and electromagnetic radiation isolation schemes.

   e. Whether to purchase equipment or develop in-house.

f. Software specifications including language, operating system, data formats, etc.

Specification of these ground rules in advance of detailed facility design is important in a situation such as that under which SXTF is being developed where design and construction is being carried out by a variety of groups who are not in daily contact with each other.

This process may take the form of:

(1) Establishment of a standards and interface committee to oversee the design process.

(2) Preparation of a design practices and interface document in advance of a detailed design which is circulated to potential vendors to ensure that it is understood and accepted.

(3) Specification of a set of software practices.

5. Production of hardware design. Each of the items in the instrume or block diagram is translated into specific types of software, hardware, interfaces, and control techniques down to the level of detail which is imposed on the hardware contractors. In translating the design into hardware it was the consensus of the facility designers with whom we spoke that it is better to purchase a commercial hardware item where a suitable choice is available, even if the cost is somewhat higher, in a version which conforms to one of the common interface schemes. That most commonly advocated was CAMAC. Another point made is that the grounding, shielding, and isolation design chosen is extremely important and should be included in the facility design practice document. In complicated facilities where different subsystems are connected together after separate development, it has often happened that the system did not play well as a whole, or in some cases did not play at all, necessitating an expensive and time-consuming fix.

6. Issuance of RFP's.

7. Construction of hardware.

8. Installation

9. Testing and acceptance. This will be done on two levels, individu subsystems and as an integrated facility. The strawman control scheme

described in the next section takes this into account in that it suggests dual controls, one set of which is part of an integrated computer-based system to be used during facility operation, and a second system which may be hardwired to be used as a backup and for acceptance testing.

10. <u>Operation</u>

3.3 SXTF CONTROL/DATA PROCESSING DESIGN

3.3.1 Control Options

One decision which must be made relatively early in the design of the SXTF instrumentation package is the degree to which control and data monitoring will be automated, i.e., carried out with the assitance of computers. SXTF is at least an order of magnitude more complicated than any previous SGEMP or other radiation test facility in terms of the numbers of parameters to be controlled and monitored, the complexity of the tests performed, and the need for close interaction between participants. Note that computer supervision does not necessarily mean automation. In fact there is a spectrum of control options which can be considered including:

1. Minimal Computer Use. All control and data recording is manually executed, i.e., by switches, lights, alarms for status functions, panel meters, or strip chart recorders for analog functions. The only computer use would be to process and analyze SGEMP and diagnostic data, recorded primarily by R7912's. This is essentially how CASINO was instrumented.

2. Computers Used for All Data Recording. Control functions are exercised manually as in (1), but scanning, processing and recording of system data will be computer controlled with a provision for operator intervention. Selected data would still be displayed through lights, meters, etc.

3. Interactive Operator-Computer System. Both facility operation and data logging would be executed through one or more computers in a real-time, interactive fashion, where one or more operators are in the control loop, exercising control through dynamic graphical displays. Which functions would be under operator control and which carried out automatically could be determined by the operator. Even in this scheme some control and data monitoring could still be carried out via hardwire links.

4. Automated. Each test cycle would be carried out more or less automatically on command by the test director. The system control computer would generate commands to check the status of the tank, satellite, photon sources, sensors, recording devices, record instrumentation settings, and calibrate data channels. If all of these are in order, it would charge and fire the pulsed power sources. After the shot, data processing of diagnostic, SGEMP and satellite behavior data would be carried out and output. Only if some key parameters were out of specified limits would operator intervention be mandated (except where a hold was dictated for other reasons). In some respects option (4) differs from option (3) in the degree of automation.

It seems likely that the sheer volume of data to be monitored and analyzed and the number of control tasks to be executed, expecially in the operation of the MBS, and in carrying out diagnostics and SGEMP data recording, will dictate a much larger degree of computerization than incorporated in past systems. The exact computer configuration is still to be determined, but at the very least it will probably include a control minicomputer interfaced to a group of front-end microprocessors.

Most large experimental facilities which have similar numbers of parameters to be controlled and monitored have adopted facility control schemes most nearly like option (3). While automation of routine functions is highly desirable, there are still many kinds of tasks best done by an operator (although perhaps fewer in a test facility like SXTF, than in an experimental facility like SLAC). The ability to operate in an interactive fashion has been made possible because of the availability of distributed computer networks consisting of one or more central computers interfaced to front-end microprocessors controlled by touch panels. All of the large facilities which we have visited were configured and operated in this manner.

3.3.2 Computer Configuration

The SXTF facility lends itself well to a distributed multiprocessor system based on one or more supervisory minicomputers controlling a group of microprocessors. There are a number of operations that must be performed in parallel. More direct control along with faster processing is obtained by using a distributed multiprocessor configuration. Such a processing scheme is faster than one based on a single computer as was the case for CASINO where all the data processing was done in a serial manner. Setting up a system based on a set of dedicated processors for related sets of tasks

allows the task control or initial data processing to be executed in parallel. In this scheme the processing time to carry out a set of tasks is inversely proportional to the number of processors employed. The particular tasks to be accomplished by each microprocessor is controlled by a program resident in the microprocessor memory. No time is lost because of multiple disc accesses often needed to execute parallel tasks on a larger minicomputer. There are four major systems that could use one or more dedicated microcomputers. These systems are tank environment, the pulsed power sources, SGEMP data and radiation processing systems, and the facility/AGE interface.

In this scheme, the microprocessor is changing the role of the large mainframe computer. Before the development of the microprocessor, systems were built with a major computer for each major task. The major task probably had minor tasks and they were incorporated within the one mainframe. The processing was completed by timesharing the memory with an overlay software solution. The different programs were read from a disc. This was an economical approach because of the high price for mainframes and memory. The type of system is still used and will continue to have applications, although in the facilities visited such systems were being replaced by the kind of distributed system described below.

Control systems that were formerly constructed with discrete integrated circuits of small-scale, medium-scale, and large-scale integration are now being designed with microprocessors (provided the speed is acceptable). A microprocessor that is incorporated in a control system gives the system more flexibility because the resident software which defines the operations performed may be readily changed. This development has been spurred by the sharp decrease in the costs for microprocessors, so that their use offers a viable solution for handling the numerous small tasks that were handled by a main frame and a discrete logic system.

Software is developed on a larger mainframe, i.e., a minicomputer, and the compiled programs are transmitted to the microprocessor systems through a communication link.

The microprocessor then controls a specific system, and can do some processing the data which is generated in monitoring the system performance. The preprocessed data from the microprocessor is then transmitted to the mainframe for final processing and display, or output in a hardcopy form.

3.3.3 Dynamic Interactive Graphical Controls (Touch Panels)

All of the species of interactive controls which we have seen are basically devices by which one or more operators can control or monitor the performance of a group of processes through a computer network. As typically employed it permits operator intervention in a multi-task system while many tasks are simultaneously being carried out independently of the operator. A touch panel has three essential elements: a means of commanding the operation of the computer network, a device for displaying information, and circuitry for communication with the computer network. An example of a touch panel, althougn not the best one, would be a computer terminal with a video display or line printer. The control element can be a computer terminal keyboard, a cursor, a light pen, knobs or push buttons whose functions are programmable. The display can be a line printer, or video monitor. Many of the newest touch panels make use of high-resolution, four-color video displays. In its most useful form, each control element of a touch panel is superimposed over the relevant status information. Thus, as a task is being executed the state of the function controlled is continuously monitored and displayed.

Touch panels for facility control and monitoring have three essential aspects.

1. <u>Computerization</u>. When the touch panel is activated, rather than executing a task directly, a computer program is called which transmits appropriate information down a data link to a process controller which performs the task.

2. <u>Selectability</u>. The functions controlled or monitored in a particular panel configuration are programmable. In most cases, touch panel systems operate in a foreground/background mode. An operator has the choice as to which systems are controlled or monitored directly through the touch panel. Other tasks may be simultaneously performed by direct computer control without operator intervention.

3. <u>Digitization</u>. Since control is exercised by computers, all operating and data recording processes must be carried out through digital interfaces.

The advantages of a computer-based touch panel system can be summarized as follows:

1. <u>Simplicity</u>. Panel contents can be tailored to contain only those functions of immediate interest or most important. Information of lesser importance can be monitored by the computer with alarms set on critical parameters without

distracting the attention of the operator, unless turned on. One can design touch panel displays in a variety of ways. One is by system. One configuration for a touch panel might contain all control functions for the vacuum system. A second design could be by process, i.e., to control and monitor all those tasks specifically required in firing a test shot. In typical designs, one has the ability to readily call up any one of a number of commonly used control and data combinations by a keyboard command, a coded magnetic card, or a hardwired button.

2. Flexibility. Changes in the detailed contents of a panel is a software problem. Usually one does not have to rewire panels or the instrumentation system when the change is made. Thus modifications to a panel can be done while the system is on-line. This feature is of considerable value during the development phase when a lot of diagnosis is being carried out to determine how a system is best operated and also because control or data needs unperceived during facility design can be readily incorporated.

3. Compatibility with the Concept of Having a Test Directors Console. A touch panel can be configured to contain that key information required by the test director to control a test. In addition, he would have the ability to interrogate different parts of the system in the case of a malfunction. One can envision a set of touch panel displays situated in different parts of the facility programmed for the most part to operate in a read-only mode, except for the units where a particular control process is performed, and then only for that process.

4. Economy of Facility Operation. Generally when a large facility has gone from a manual mode of control to a computer-based, touch panel scheme of operation the number of operators and the number and size of control rooms has diminished. Only one operator is required at LAMPF who is responsible for $\sim 10^4$ control tasks and data channels. Considerable simplification in the screen rooms shown in Figure 4 of Reference 10 can be achieved if the numerous racks and control consoles were replaced with a touch panel display system. To be sure, a backup, hardwired control and data system is required, but it might be put in a separate screen room while the facility operator and test director could be put in the SGEMP data room for optimum communication.

5. Display Flexibility. As the touch panel display is usually computer generated, one can have much greater flexibility in the way information is presented if compared to a collection of dials, switches, lights, and digital displays, especially if the touch panel display unit is a modern high-resolution four-color type.

6. Diagnostic Capability. As the touch panel is in fact a computer terminal, it can be programmed to execute facility diagnostic routines directly in case of malfunctions. One of the most interesting aspects of the LASL Plutonium Reprocessing Facility Control System was its ability to generate system functional diagrams, including status data and identification control points, by which malfunctions can be pinpointed. In older facilities one has to pull out and trace circuit malfunctions through printed functional and circuit diagrams. This is not always an easy task in a complicated facility.

On the other hand, there are disadvantages in going to a touch panel/computer scheme, including:

1. Cost. Although no firm figures were obtained, the cost of a computer/touch panel control scheme will undoubtedly increase facility costs because of a need for additional computing capability, analog-to-digital interfaces and software development.

2. Standardization. Efficient utilization of this scheme requires a fairly high degree of standardization in the control and data links and signal conditioning and process control interfaces. One will probably have to carry interfacing down to the individual sensor and transducer level which will undoubtedly impact on the cost and availability of sources of supply, especially where such standardization goes against industry or manufacturing practice.

3. Complexity. Added circuitry in the form of A/D and D/A converters, data links, multiplexing circuits, etc., are required to condition circuits signals for computer control and interrogation.

4. Need for Dual Controls. A hardwired control and data monitoring unit will probably be required in addition to the master control for subsystem testing, especially during the development phase when the requirement to operate each subsystem independently is important.

3.4 CONCEPTUAL DESIGN

The conceptual computer design presented in Figure 1 is essentially a translation of the functional diagram presented in Figure 3 of Reference 10; it reflects current design practice in instrumenting large multi-task facilities. It is necessarily vague as to actual hardware. These only can be determined after a detailed tabulation of control and data requirements. In this scheme at the lowest level will be a set of microprocessors carrying out specific tasks. It is to be determined whether the intermediate processors will be supervisory microprocessors with expanded memory and I/O capability, or minicomputers. This choice will depend on the number of tasks to be controlled, the amount of data processing required, and the speed at which such processing has to occur. In terms of the control options discussed in the preceding section, the design presented is closest to (3) in that it is a dynamic, computer-based operating system in which one or more operators are part of the control loop and where important functions are under direct operator supervision while other tasks are executed by computer. Whether this scheme is optimal for SXTF can only be determined after evaluation of some of the advantages and disadvantages described below, in the light of facility requirements.

According to the classification presented in Reference 11, the proposed system is a modular, distributed, multi-task, computer-based network. Control of individual major subsystems would be exercised either through a set of subsystem control consoles or possibly through a single master panel. The system is modular in that standardization is pushed to the highest level possible in the design and that its hardware implementation will probably be based on a single family of microprocessors and minicomputers such as the DEC 11 series. Such a choice would simplify design, programming and interconnection. It is a multiprocessor system because it contains many units, each functioning cooperatively, as part of a coordinated system. It is also a distributed system since each processor would have its own executive and perform specific fixed tasks described below as part of the overall system. This system is also a network in that it contains decentralized independent computers which are connected via data communication links which are operated under a defined communications protocol.

In the diagram the facility has been organized into its major logical components; tank environment, radiation source control and diagnostics, SGEMP/radiation measurements, and facility/AGE interface. In addition, a master facility computer has been provided to allow for the possible operation of this facility by one or more operators at

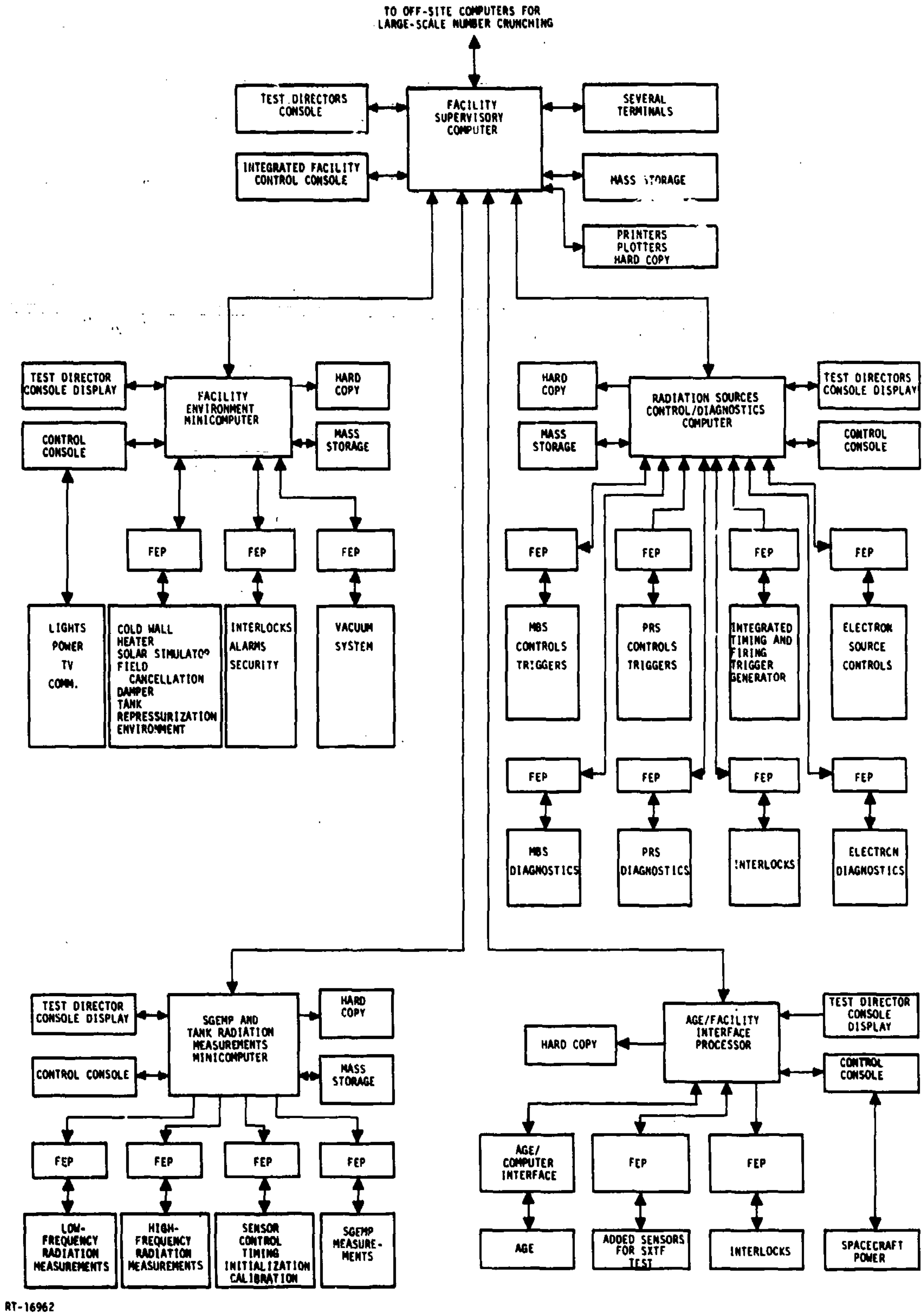

Figure 1. Conceptual computer design

a single console, and to provide the computer interface for the test directors console. In this design, data processing is an integral part of the facility instrumentation plan and not broken out separately. Communication between subsystems is by the computer network.

The scheme provides for a computer hierarchy which at the lowest level is based on a set of front-end processors such as DEC LSI-11's or Motorola 6800's, each of which performs specific, dedicated tasks. These include exercising fixed control operations such as the opening and closing of valves, changing and monitoring pot settings, handling interlocks, operating the machine timing and firing network, etc., as well as carrying out data logging as commanded, and possibly doing preliminary data processing. While a somewhat arbitrary arrangement of FEP's has been presented in this conceptual design, the actual assignment of individual FEP's including specification of numbers and configurations to specific tasks awaits the detailed facility design. An advantage of the proposed scheme is that functions can be added or deleted without significant change in the way the facility is interconnected. In addition, the exact configuration of a microprocessor in terms of memory and I/O capability can be tailored to fit the particular tasks controlled. During the development, attachment of a terminal to a microprocessor would permit local control. A provision for parallel hardwire controls will also be desirable.

On the next highest level is the subsystem control computer. This is specified as a minicomputer, it could be a large microprocessor if only a single control computer is needed. Again the specific assignments could be reconfigured. The role of this second level computer will be to provide overall subsystem control (exercised through an associated terminal), controlling the interactions and interlocks between the FEP's, and recording and processing data related to the operation of the subsystem. In addition, the subsystem computer might carry out performance diagnostics as well as providing the capability for a quick-look data analysis. Each subsystem computer would contain mass storage devices for limited data storage, as well as the capability of generating hard copy. More extensive number crunching would be done either on the facility master computer or at a larger off-site computer connected to the system by a dedicated link. While the subsystem would normally be operated through its touch panel, provision will probably be made for a parallel hardwire set of controls such as shown in Figure 4 (Ref 3), both as a backup in case of computer malfunction and for testing during facility shakedown and in case of instrumentation failure. Provision of a

subsystem control capability in a multi-task facility such as SXTF is important as individual subsystems will probably be developed and brought on-line independently.

At the highest level would be the facility master computer. Its functions might include the capability of exercising overall facility control, providing the interfaces to the test directors console, directing communications between subsystems, carrying out archival data processing and report generation, storage of archival data from the various subsystems, and controlling communications with outside computers. Its probable configuration would include extensive mass storage capabilities such as large disk memories, tape drives, and a comprehensive hard copy capability, including line printers, hard copy units, and digital plotters. Since it would be a multi-task computer, it could be used for system software development. Terminals could be located throughout the facility connected to this computer and used for software development and data analyses.

No specific determination of the nature of the links interconnecting various components can be made at this stage of the design. One reason for standardizing the design at the highest possible level with products from one manufacturer would be the resultant simplification in interfacing. The links themselves can be conventional hardwire or fiber optics if it is decided that it would be advantageous as part of an overall facility noise reduction scheme (q.v. section 4.2.2.3). Both schemes are presently in use. Also to be defined are the necessary interfaces between the FEP's and specific types of hardware. These interfaces should be based either on a manufacturers standard or some industry-wide instrument interface scheme such as CAMAC. For example, one might purchase items such as ADC, DAC, and multiplexers from DEC, if their computers are used, provided that a sufficiently large number of signal-conditioning devices are available from them. The exact nature of the interfaces required can only be determined after a detailed instrumentation list is prepared and cleared with prospective vendors.

In deciding whether this strawman design should be applied to SXTF, the following advantages and disadvantages should be noted. The advantages of the proposed scheme include:

1. Flexibility. Because of the modular design imposed from the hardware interface up to the control level, it would be relatively easy to reconfigure the hardware content of the system, or the manner in which it operates, without extensive rewiring. It is relatively easy to add or modify software packages as facility requirements change.

2. Convenience. The dynamic-interactive control scheme simplifies the task of facility operation. Only those tasks of immediate interest need be looked after by the operators. Other activities are carried out under direct computer control.

3. Simplification of Controls. Because of the power of the dynamic graphic method of control, fewer operators are required to operate a facility. Conceivably, all the facility controls could be put into a single screen room. The backup hardwire control system could be put into a separate screen room or in the same room. In the facilities which we visited both options have been used.

4. Enhanced Communications Between Participants. As the various subsystems are connected together by the computer network, each group can monitor the state of the whole system through a set of graphic display terminals which might, for example, be read-only versions of that provided for the test director.

5. Suitability for the Test Director Concept. The test director's console will be connected to the master facility computer giving him the capability of monitoring the performance of critical elements of the entire system during the test, receiving alarms and running diagnostic programs for fault detection.

6. Ease of Maintenance. By enforcing a modular, standardized design on facility instrumentation and software the maintenance problem is simplified. This is especially important in a facility where the groups are responsible for design and construction may not be the same as those who will maintain, modify, and repair the facility. In addition, the system could be self diagnosing if a set of diagnostic programs were added to the facility operating system.

The disadvantages of the proposed design include:

1. Cost. Additional hardware is required to interface instrumentation to computers, because of the need for multiplexing, analog-to-digital conversion and signal formatting. While standardized schemes such as CAMAC now encompass a great many kinds of process controls, providing a digital capability can be costly. There is also the additional cost for computers and software development. All of the facility designers with whom we talked

agreed that software costs are often the major part of any computer system. However, software costs can be minimized if software development is carried out as part of that for an overall operating system which includes these functions for which a definite need has already been established, such as those required for data analysis of diagnostic and SGEMP information. It is recommended that DNA not pay for additional software development for stand-alone systems without considering its relevance to SXTF requirements.

2. Difficulty in Imposing Standards. The interface and design practices chosen by the facility designers may conflict with those of a prospective vendor. In that case one has three options: seek another vendor, pay for incorporation of facility design into his hardware, build a nonstandard interface to connect a particular device to its associated FEP. Use of a standard interface scheme such as CAMAC will minimize this problem.

3. Additional Complexity. An additional layer of hardware is required between the particular device to be controlled and the controller.

3.5 STANDARDIZATION

The desirability for standardization should be evident in a facility such as SXTF, that will contain large quantities of similar instrumentation. However, standardization will be complicated by the fact that many manufacturers will provide instrumentation for the facility. It is necessary for close supervision by the instrumentation integrator to ensure that equipment obtained from different sources is compatible and conforms to the overall design. Unique front-end hardware may be necessary to perform particular functions that must be monitored and controlled. However, the controlling or recording of these functions become less unique and more common as they are transmitted back to the user. This is reflected in the conceptual facility computer design presented in Figure 1.

As an illustration, consider the measuring of a temperature or pressure. Both represent analog data. The temperature in a system is measured with a thermocouple, the pressure with an ion gauge. In both cases the output of each sensor generates a voltage which must be conditioned and digitized in some manner to produce a readable number for the end user.

Another type of example might be the closing of a valve in the vacuum system or the turning on of a vacuum pump heater. The fact that the valve closed may be

feedback by the action of the valve, a switch which is also coupled to a relay. The current generated in the heater may also be sensed by relay activation. In both examples the operator needs to know the status of a particular device. In this regard it is better to use sensors which actually depend on the operation of the device rather than one which infers its behavior.

The point of commonality in these two sets of examples is that numerous tasks which must be carried out in the facility can be reduced to a relatively few general types.

Facility data collection and control tasks can be characterized in several ways, in increasing levels of complexity. For example, one can distinguish between the following:

1. Status data, essentially binary, i.e., on-off, open-closed.
2. Analog data, not only is the status important but its value is also important, i.e., temperature, pressure, dose.
3. Analog array data, a two or higher dimensional manifold of values, such as an SGEMP waveform. In a sense (2) is a subset of (3) where the value of the parameter monitored changes relatively slowly with time so that only the current value is of interest. A similar categorization can be made for control tasks.

A second method of organizing data tabulation is by a data or control link as shown schematically. This is essentially an operational classification. Such a scheme

STIMULUS	SENSORS	TRANSMITTER	LINK	RECEIVER	PROCESSING	OUTPUT	CONTROLLER
TASK	TRANSDUCER	RECEIVER	LINK	TRANSMITTER	TRANSDUCER	COMMAND	a) HUMAN b) COMPUTER c) OTHER SYSTEM

will be helpful in identifying areas where hardware commonality permits standardization. In carrying out the link analysis of data and control processes one can characterize them by:

1. The type, digital or analog;
2. The nature of the sensor producing the signal, or transducer executing a task;
3. The form of the output, i.e., voltage, current, differential, high/low impedance, etc;

4. If digital, the number of bits, logic levels, pulsewidths, bit word rates, serial or parallel transmission;

5. If analog, characteristic frequencies, amplitudes, pulsewidths;

6. Estimated number of channels;

7. Scan rate;

8. Significance, how important is that data for interpreting test results?

9. Capability for generating noise or its noise susceptibility.

10. Interactions with other systems.

11. Required auxiliary functions such as calibration, timing, etc.

Thus, the categorization of required control tasks and data needed to translate a system functional design into its hardware realization can be carried out in a variety of ways. These include: by function (i.e., identifying the instrumentation required to carry out each identified task in the facility); by type, as most data and control tasks can be grouped according to a relatively few categories described above; and by process providing an end-to-end description of how each task is carried out as in the link analysis. For complete definition it would probably be beneficial to analyze the facility instrumentation requirements in each one of these ways, as well as from any other point of view whi proves useful. Such a program should be carried out by the entire SXTF design community rather than left to a single group.

After identifying areas where common schemes of process control or data management can be applied, the next step in the facility design process is to identify to what degree standards can be imposed on the interfaces between the FEP's and particular items of instrumentation. This requires a detailed knowledge of common design practices in each of the instrumentation areas. It will be difficult to obtain instrumentat in tandard packages, or with novel control or data monitoring features, from a given manufacturer along with firm guarantees of reliability and performance without seriously increasing its cost. Therefore, facility design practices should be based on industry-wide, accepted standards wherever possible. Choosing instrumentation desi according to one of these standards will ensure that a relatively large variety of equipment from more than one source for carrying out particular functions will be available, that newly developed instrumentation will be packaged to conform to one of these standards, and that the need for design and construction of special interfaces will be minimized.

Both Government agencies and manufacturing associations have created sets of standards for the construction of various types of instrumentation. By standardization we mean at a minimum commonality in regard to voltage and power requirements, packaging and power connector assignments and location.

Several of these instrumentation standards will probably be used in SXTF design. The NIM (Nuclear Instrument Module) standards were introduced by the AEC and NBS to provide maximum compatibility between nuclear pulse instrumentation produced by various manufacturers (Ref 12). The standards define characteristics as module and bin dimensions, power connector location and pin assignments, as well as supply voltages and allowable current for each supply voltage. NIM standards do not prescribe standard circuits, functional instrument specifications, or required fabrication methods. However, there is a set of NIM preferred practices which are recommended by the NIM Committee to define linear signals, logic signals, and preamplifier connections which are typically followed by different manufacturers of the same type of module. It is likely that NIM compatible equipment will be used to design the timing and firing circuits, both for the radiation sources and for controlling the SGEMP and diagnostic data recording systems.

A second common instrumentation and interface standard is the computer automated measurement and control (CAMAC) standard. It was developed to serve for interfacing transducers and other devices, packaged in standard modules to digital controllers for data transfer, measurement and control. CAMAC standards have been adopted by the IEEE and are given in References 13 through 16. These standards contain specifications on modular construction, and the type of power and signal distribution. This standard has been increasingly adapted to interfacing process control instrumentation to digital controllers and is an especially attractive system for interfacing individual instrumentation to FEP's.

Many types of CAMAC compatible instruments are available, including:

1. Drivers: motor, synchro, relay, meter, peripheral
2. Counters: real time, dead time, up-down, interval
3. Converters: A to D, D to A, BCD-Binary, Binary-BCD, V to F
4. Controllers: Stepping motor, power supply, crate, branch
5. Others: Encoders, registers, trace units, generators, multiplexers, digitizers, DVM's, Buffers, Clocks, Fan Outs, Latcher, Gates

6. Computer interfaces to common microprocessor and minicomputers, as well as microprocessors packaged in CAMAC modules. New CAMAC compatible functions are constantly being developed.

The advantages in using one of these instrumentation schemes include:

1. Flexibility and interchangeability of instruments internally and between subsystems.
2. Ready optimization of instrumentation systems.
3. Ease of restructuring of instrumentation systems.
4. Minimization of the need for maintaining extensive inventories of extra modules.
5. Deferred obsolescence; new instrumentation is likely to be built in packaging compatible with one of these standards.
6. Ease of servicing and reduction of down time.
7. Availability of blank modules into which custom hardware can be inserted.
8. Reduction of design effort because the packaging and voltages are already supplied.
9. Availability of numerous commercial instruments from many suppliers.
10. Is a modular system with fundamental units that can be configured in different ways to form equipment assemblies to carry out specific processes.

Additional specific features of the CAMAC system include:

1. The functional units are constructed as computer independent modules and mounted in a standard crate.
2. The mechanical structure is designed to utilize the high component package density possible with integrated circuit packages and similar devices.
3. Direct connection from each module to a standard data way. This highway which forms part of the CAMAC crating conveys digital data, control signals and power.
4. The design is such to permit ready assembly of a system consisting of a crate and modules for connection to an on-line digital computer.

5. Standardized protocol and hardware specifications for the parallel or serial transfer of data between the CAMAC driver and one or more crates.

6. External connections to modules which conform to the digital or analog signal standards of associated transducers, computers or to the recommendations given in the standard.

In addition to the NIM and CAMAC standards, others have been written which are applicable for the transmission of digital data between terminals. These include the IEEE standard 488 for transmission of parallel data (Ref 17), EIA standards RS232, RS269A, 422, and 423 for transmission of serial data.

Other possible standards may be chosen. For example, if one decides on using a set of minicomputers and microprocessors from a particular manufacturer such as DEC, then data and interface standards which are manufacturer specific may be chosen. This was the path taken in the CASINO design. In this case the data transmission links would probably be manufacturer specific. One problem with this approach is that all required interface, signal conditioning, and process control hardware may not be available in a system compatible form.

The simplest form of a digital communication link is the serial transmission of data over a common conductor. This conductor may either be hardwire or fiber optic. Most of the distributed multiprocessor control systems which we examined were connected together by serial links. Provided that the frequency demands for data transmission are within the capability of a serial link, all communications between microprocessors and supervisory computers should be conducted with such links. Using an industrial standard for the transmission of such serial data should be a requirement for SXTF.

It will be advantageous to standardize the computer system in the facility in regard to the control computers as well as the front-end microprocessors. The advantages of such a scheme include:

1. The software language which is the same.

2. Software documentation would be reduced because of commonality in drivers and other system requirements.

3. Common interfaces could be used in most cases.

4. Common spare parts can be purchased that would allow for a board changing type repair.

5. Software development could be done on one of the terminals connected to one of the higher level minicomputers.

The disadvantages in using microprocessors which are both common within themselves and also with the facility control minicomputers include:

1. Specific systems may have too much capability, i.e., some systems could use smaller, less expensive microprocessors.

2. There may be problems in convincing a vendor to use the facility sponsored microprocessor.

In summary, the probable design of the SXTF instrumentation package is such that a great deal of standardization in regard to signal conditioning, interfacing, and data links and computers can be anticipated. To the greatest degree possible, such standardization should be carried out using one of the manufacturer or industry-wide accepted schemes. Whenever possible, commercial hardware should be purchased which is compatible with the standardization scheme chosen.

4. TOPICS IN DATA TRANSMISSION AND RECORDING

4.1 INTRODUCTION

Because of a perceived need for dielectric isolation of test objects during radiation and electromagnetic simulator testing, the SGEMP and EMP communities have played a leading role in the development of wideband fiber optic and microwave dielectric data transmission links. Such links will probably play an important role in transmitting SGEMP and fast diagnostic data in SXTF. However, there are other instrumentation areas where dielectric isolation and minimization of noise coupling may be important. These include controlling and monitoring of the pulsed power sources, transmitting data and commands between the satellite and AGE, and as an element in a general facility grounding, shielding and penetration plan.

In this section, we present a discussion of the advantages and disadvantages of replacing some or all of the hardwire connections between different portions of the facility with data transmission systems which employ dielectric links instead of cables. Included is an assessment of the state of the art and an identification of generic links which might be required and a discussion of specific applications.

The presently available wideband fiber optic link is adequate in regard to bandwidth, but in many respects unsatisfactory in regard to radiation tolerance, dynamic range, linearity, and size. As the state of the art in these systems is advancing, it is important to assess what sort of units might be available for SXTF before deciding on whether to fund a special development program. Herein is presented a detailed discussion of present technology in regard to performance and radiation tolerance, problems to be faced in operating such links in the SXTF radiation environment, current technology development, an identification of techniques for improving the radiation behavior of such links, and projected advances in related optoelectronic technology which may be applied to produce links with performance superior to that of units presently under development.

Given the volume of data to be processed in SXTF, much of it will need to be digitized and processed by computer. Previous studies have shown that presently

available transient digitizers of even moderately wide bandwidth are relatively expensive. Moreover, there is presently only one transient digitizer commercially available for high frequency (> 100 MHz) SGEMP and diagnostic data. This unit is the Tektronix R7912. While it is satisfactory in terms of performance, it is rather expensive (~20K each). As there is a projected need for large numbers of channels of high frequency capability (50 to 100), any advance in technology which could provide the same capabilities at significantly reduced cost would substantially reduce system costs, and if low enough could lead to reevaluation of some aspects of data recording such as in machine diagnostics. In fact, new methods of transient data digitization applicable to SXTF are actually being developed for the laser fusion, nuclear weapons diagnostics and nuclear physics communities based on advances in integrated circuit technology, especially that incorporating charge controlled devices. A summary of this work is presented.

4.2 APPLICATION OF DIELECTRIC ISOLATION TECHNIQUES IN SXTF

4.2.1 Advantages and Disadvantages

In this section possible applications of dielectric data links in SXTF are examined. There are two kinds of dielectric links of this type. The more commonly used of the two is one in which a light signal is transmitted down a glass or plastic fiber or fiber bundle. The second is one in which the signal is incorporated as amplitude modulation on a microwave carrier transmitted down a dielectric waveguide. Systems of both types (Refs 18,19) have been used for transmission of SGEMP data from a test object while maintaining its electrical isolation. However, the presently available fiber optic systems are currently superior to the microwave telemetry links in nearly every respect, such as bandwidth, size, convenience of operation, so that they have supplanted the latter except for one possible application discussed below. Microwave systems currently in use have large transmitters and receivers that consume considerable amounts of power and therefore cannot run very long on batteries (three hours for the EG&G model). The dielectric waveguides are stiff, bulky, and hard to handle. The signal bandwidth of currently available systems are a factor of two or more lower than that of fiber optic systems. However, improvements in terms of battery life, system bandwidth, and transmitter size have been announced (Ref 20) which make the use of these systems more attractive and therefore progress in this area should be monitored. At present the wideband fiber optic systems are the prime candidates for transmitting

high frequency multi-hundred MHz SGEMP and diagnostic data, although other techniques are being considered (Ref 10). Because of their importance, a separate assessment of the state of the art of these systems is presented in the next section. The balance of this section will discuss possible applications of dielectric data links to other areas of SXTF instrumentation. This survey is based on facility visits to LASL, L^3, and SLAC where this technique has been used to solve instrumentation problems similar to those to be faced in SXTF as well as with members of the spacecraft manufacturing community (TRW, Ford, Hughes).

Note that we are not claiming here that all data transmission should be done via fiber optic links. However, this is a rapidly evolving technology which is being beneficially applied to facilities with similar noise problems created by numerous large pulsed power sources. Therefore, one should seriously consider this option in instrumenting SXTF, especially in designing a facility grounding and shielding scheme without dismissing it out of hand.

There are several advantages in employing fiber optics for transmitting data and control commands back and forth between the screen rooms and the rest of the facility. These include:

1. Dielectric Isolation of Electronics and Test Objects. Noise cannot be coupled into dielectric cables and transmitted to components or the test object. This factor of dielectric isolation is of prime importance in the application of fiber optics and dielectric links to SGEMP and EMP testing.

2. Noise Immunity. No electromagnetic radiation can couple into the links themselves, thus the requirements for carefully shielding cables is minimized. In addition, the need for providing cable troughs or complicated penetrations into screen rooms through which cables have to be snaked and potted is also minimized.

3. Voltage Isolation. Different parts of the system instrumentation package, especially those portions connected with the PRS and MBS or the backscatter grid will be at dangerously higher potentials referenced to facility ground. The use of fiber optic links or at least optical isolators will prevent propagation of unwanted high voltages between subsystems. Should breakdown or sparking occur, resultant transients would not be propagated down associated signal or control cables. The voltage isolation provided is a safety factor protecting personnel.

4. Subsystem Isolation. If a grounding and cabling scheme for the facility is developed in which different subsystems are electrically isolated, then they can be developed and put into operation independent of each other, while minimizing the possibility that unforeseen ground loops will interfere with system operation when all the parts are put together. This can be a significant problem in a complicated system such as SXTF in which different portions of the facility may be developed by different groups and be brought on line at different times.

5. Simplification in Computer Requirements. Should digital data be transmitted over fiber optic lines, their relative noise immunity will minimize the need for computer hardware and software for error analyses.

On the other hand, fiber optic systems at their present stage of development and commercialization present some disadvantages. These include:

1. Added Complexity. Between each transducer/sensor and the corresponding control/recording device one must interpose a fiber optic transmitter and receiver. If all else remains the same, this increases system cost; however, if grounding and shielding can be simplified and the attendant electronic circuitry can also be simplified because of a relaxed need for noise suppression, then some of the cost of fiber optics can be offset.

2. Availability of Commercial Hardware. The ideal situation would be one in which suitable hardware could be purchased commercially at low cost. At present most fiber optic systems are custom built for particular applications. There may be little off-the-shelf hardware which could be directly incorporated into SXTF. However, most of the instrumentation to be controlled or monitored at SXTF is not facility unique with the possible exceptions of the complicated timing and firing requirements for MBS and the need to record data in a radiation environment. In our visits to LASL and L^3 we learned that fiber optic systems of types required to perform most of the data transmission and facility control functions for SXTF have been created for these facilities (Ref 4). Thus, it may be possible to directly copy existing technology developed under Government funding minimizing development costs. The adequacy of existing fiber optic links also depends on facility design. The more standardized the system in terms of interfaces, the fewer types of links would be required; i.e., by forcing standardization down to a

very detailed level, at an individual transducer or sensor level, data transmission requirements would correspondingly be simplified. Moreover, this is a technology which is rapidly evolving. One point which was made by the system designers with whom we talked was that commercial versions of hardware developed in-house, such as serial links for communication between computers, should be available in the near future.

3. Cost. At present fiber optic links are relatively expensive, if compared to the cable it replaces, i.e., a single point-to-point digital data link capable of transmitting data three hundred feet at a ten-megabit rate costs between \$300 to \$1000. The cost of such links should go down significantly as the market increases. However, a single link of this type has a sufficient transmission rate to multiplex many channels of low frequency data; therefore, the incremental cost in using fiber optic systems may be a small increment compared to the advantages gained and overall facility cost.

4. Radiation Sensitivity. Fiber optic electronics, and the fibers themselves are sensitive to the x-rays and simulated space electrons which will be sprayed into the test chamber. This is discussed in detail in the next section. Systems of this type which have to operate in the vacuum tank may have to be hardened. While there are prototype links available to perform all anticipated kinds of data and control functions (although not necessarily available as off-the-shelf items) little has been done to harden any of these except those developed for SGEMP measurements. However, the difficulty in hardening lower frequency links will be less than that for high frequency ones. This is true for several reasons.

   (1) They do not have to operate during the radiation pulse. However, circuit protection must be included to prevent burnout or upset of electronics. The propagation of radiation-induced transients through the links must be eliminated. This may be done automatically because the bandwidth of the transmitting and receiving electronics will, for several of the systems discussed below, be too low to respond to the high frequency transient radiation pulse. If this is not the case, filtering may have to be included. On the other hand, these links may have to be well shielded from the simulated space electron environment.

(2) Possible transmitters are radiation insensitive. Low frequency systems for transmission of status data or control operations have been built with a transmitter which is nothing more than a small light bulb (Ref 4).

(3) The dynamic range and linearity of light sources such as LEDs is much greater than that of the laser diodes used in the SGEMP transmitters. Thus, less amplification would be required. The radiation sensitivity of the amplifiers used in the presently available SGEMP links is one of their weak points.

In some cases (e.g., as a command link for the spacecraft to replace the RF command uplink) the fiber optic receiver will have to be placed in the radiation field. As this is the reverse of the normal SGEMP case, an assessment must be made of the operation of candidate receivers in an SXTF environment.

In summary, an assessment should be made of the problems involved in operating candidate fiber optic links in the SXTF environment as the different types are identified. As a first cut, one can analyze the radiation tolerance of the set of fiber optic systems discussed in Reference 4.

If it is decided that the advantage of fiber optics systems such as noise immunity, high voltage isolation, and subsystem isolation are desirable, one can envision providing a set of general links which would be adapted to particular applications. The degree to which these links can be applied depends on the degree of standardization imposed on design; i.e., at what level commonality and data recording in control is incorporated in different facility elements. A set of representative links would include:

1. A relatively simple binary link to control and monitor on/off functions and state data for valves, heaters, pumps, relays, interlocks, etc.

2. A low frequency analog data link for controlling and monitoring slowly changing function and data such as temperatures, pressures, program enable power supplies, or integral data from machine diagnostics or dosimetry.

3. A serial or parallel digital data link to transmit multiplex digital data between front end microprocessors and control minicomputers or between a satellite and the AGE. It is not clear, but possible, that the same link could perform both functions. The exact nature of this link will depend on the detailed format of the information to be transmitted, i.e., the number of channels of data, the interrogation rate, nature of signals scanned, logic type and level, manner of transmission to interrogating computer.

4. A moderately high frequency analog data link with a bandwidth in excess of 10 MHz using an LED-driven transmitter.

Prototype versions of links to perform all of these functions have been developed and are being applied at systems such as ANTARES and SHIVA laser fusion devices. In addition, commercial versions of the fiber optic equivalents of some of the more commonly used interface schemes to connect computers to hardware should be available before SXTF instrumentation construction has begun.

4.2.2 Specific SXTF Applications

Based on our understanding of the possible structure of the SXTF facility there are several areas where the use of dielectric data links are feasible. These include: satellite-AGE interface; controlling and monitoring the performance of the MBS or PRS; transmitting machine and radiation diagnostic data (especially peak and integral quantities such as total dose, charging voltages or integrated diode output); in implementing facility environment control (of the vacuum tank, backscatter grid, etc.); and as part of a general grounding and shielding design based on isolating individual subsystems to minimize noise coupling and ground loops.

We will now discuss each one of these applications in turn.

4.2.2.1 Satellite-AGE Connection. In order to determine the SGEMP response of a spacecraft which normally would be exposed to a threat in free space it is contended by most analysts that it is necessary to decouple the responses of the test object from those of the tank and cabling. Therefore it is felt that the satellite must be dielectrically isolated from its surroundings. This has been the principal incentive for developing high frequency, radiation tolerant, fiber optic data links. To be sure, there is some question as to whether and to what degree such isolation is necessary or whether alternative schemes such as inductive loading of cables might work.

However, when a satellite is placed in a test chamber for a system or subsystem test, a variety of hardwire connections are made to it. Connections between the spacecraft and the tank are typically made to supply power to monitor and control spacecraft behavior, to monitor and control payload operation, and to more closely follow behavior during qualification testing with extra sensors installed in the tank or on the spacecraft.

We briefly summarize how each one of these connections is made in terms of current practice and assess whether they might be replaced by a connection which

maintains dielectric isolation. The solution to the problems posed in this discussion will only be determined after consultation between the SGEMP analysts, spacecraft manufacturers, and instrumentation specialists as to what measurements are necessary and practicable. Presumably these problems are being addressed in more detail by TRW.

1. Power. Typical spacecraft require 20 to 60V dc at currents of up to 50 amps. A current generation communications satellite such as INTELSAT V may require as much as 100 amps. This is supplied by a hardwire umbilical. No practical means of transmitting this power via a dielectrically isolated link has been identified. Some consideration has been given to powering the spacecraft through its solar cell panels. Such a solution has at least two difficulties. Qualification model spacecraft do not normally possess a full complement of solar cell panels. This is not an insurmountable problem. One probably wants to test the spacecraft with a full complement of solar cell panels as they represent a major component through which SGEMP-generated energy may penetrate into the structure. Normally, in thermal-vacuum tests the solar cell panels are not illuminated. Often they are not even attached to the spacecraft during such tests (especially in the case of three-axis stabilized satellites). Sometimes spinners are tested with an illumination of less than one sun with some panels in place. The test engineers with whom we spoke had serious questions about maintaining the thermal balance of a spacecraft in a thermal-vacuum chamber when subject to a one-sun illumination. The most feasible scheme for supplying power to the satellite during a photon test that we have identified would use a retractable umbilical. Satellites have the ability to operate on battery power while they are in eclipse. This is a period of approximately one hour. One could envision a procedure where the spacecraft power is supplied hardwire until shortly before a shot. The power umbilical would be removed at the start of count-down and the behavior of the spacecraft would be observed for a period long enough to make sure that it is operating properly on battery power. After the shot is fired initial diagnostics would be performed to look for gross malfunctions (estimated to take about thirty minutes or so for FLEETSAT). External power would then be restored.

2. Status and Control Data. Subsequent to launch the performance of a spacecraft is controlled and monitored by a set of RF links. These are typically S-band (2.5 GHz) for military satellites, although they can be UHF ($\sim$ 0.3 GHz), X-band (8 GHz), or K-band (16 GHz). Through these free-space radio links properties such as the thermal balance, attitude, rotation rate, power, etc., are monitored and kept within specifications. Housekeeping data is typically telemetered at relatively slow rates of 1 kilobit. Some sensor or communications data is transmitted at significantly higher rates of the order of 50 kilobits or more. The logical method for monitoring this data in SXTF during a test would be through the RF links. However, TRW has expressed some questions about problems which may arise in operating these links in the SXTF tank. This opinion is somewhat surprising as other manufacturers such as Ford routinely operate these links in a thermal-vacuum test. The present alternative is to bring this data from the satellite to the AGE via hard lines which in some cases may be waveguide. It is conceivable that this status and control data can be brought out by one or more dielectric links, preferably of the fiber optics type if one can extract the digitized data from the microwave carrier or if the telemetered data is coupled into the fiber optic link before incorporated onto the microwave carrier. A less desirable alternative would be to use a microwave dielectric data link. The fiber optic link itself might be one similar to that used to transmit data between front end microprocessors and a controlling minicomputer. Fiber optic and microwave links with desired frequency characteristics undoubtedly exist. However, several problems must be addressed before such techniques can be adopted. These are:

a. A means must be provided to couple data and command signals normally telemetered through the RF links into the dielectric links. Thus normal circuitry of the spacecraft might need to be modified or special interface hardware might have to be provided.

b. It can be seen that one needs to provide at least two links which may be identical. One would transmit commands from the AGE to the spacecraft and the second would transmit status data to the AGE from the satellite. It is not clear whether these links will need to have a multiplexing and demultiplexing capability or whether AGE and spacecraft circuitry could be used.

c. The radiation tolerance of the candidate links will have to be determined and they may need to be hardened. At least part of this effort is novel as it will involve hardening the receiver as well as the transmitter.

d. Space will have to be found for the transmitter and receivers in or near the satellite such that their presence creates a minimum perturbation. The space problem will be even more critical if dielectric microwave links are used as transmitters and receivers are larger. One possibility is placing transmitters and receivers at the location of the dummy boxes which are usually put into qualification model spacecraft replacing the redundant set of electronics normally present in an operating spacecraft.

3. Additional Sensors for Test Purposes. During system and subsystem qualification tests in which satellites are severely stressed, additional sensors are placed in the spacecraft to monitor its behavior. The connections between the spacecraft and the AGE test sets are typically hardwire or waveguide. For example, during the testing of INTELSAT V approximately 600 channels of data were monitored (including parameters normally telemetered to earth through the RF downlink plus those added for the test) of which 400 were hardwired. In testing DSP additional data channels included 50 devoted to ordnance, 50 thermocouples, and 20 radiometers. In addition, hardwire connections are often made to the spacecraft's attitude monitoring sensors (sun, earth) to simulate orbital motion. On top of all these there are additional lines to monitor the performance of the payload. It is to be pointed out that these extra sensors are added during qualification tests to ensure that the spacecraft will perform as designed during any permitted combination of environments. It is possible that many of these extra sensors will not be needed during a SGEMP test in SXTF as other environmental stresses will not be simultaneously applied.

Most of these environmental data channels record status or relatively slowly changing analog data. It should be possible to monitor their behavior through a relatively few dielectric data links if such data can be multiplexed. Again, one may have to provide interfaces to multiplex and digitize data normally transmitted in a parallel and analog fashion and to demux this data before input to the appropriate AGE test set or computer. In addition a place on or near the spacecraft will have to be found for the signal processing and

multiplexing, electronics and the fiber optic transmitters. Such electronics may have to be hardened to survive the x-ray pulse and the space electron simulation such that they recover to transmit required status data after stress and not propagate disturbances into the AGE. Whether a different link or links must be developed for each satellite type or whether a universal link can be provided as facility-furnished equipment awaits further definition on the part of the spacecraft operators as to data requirements and a determination on the part of the facility operator as to the desirability of furnishing such links which would be needed only for a test at this facility.

4. Payloads. It is likely that during SXTF testing, the satellite payload, i.e., transmitters and receivers on communications satellites or sensors in surveillance satellites, will also be monitored. No information about system tests on sensors were obtained during our visits to spacecraft manufacturers. The antenna output of communications satellites are tested for power levels in an anaechoic chamber and for pattern on a test range sufficiently large so that receivers can be placed out of the near-field pattern of the antenna. Antenna testing is not normally carried out during the thermal-vacuum test. It does not seem practical to carry out either test using normal procedures in the SXTF vacuum tank. An additional test which is performed to monitor the output of the antenna is through a hardline connection (coaxial cable or waveguide) coupled to the antenna feed. A scheme for carrying out such a test was described in Reference 21. For SXTF, the hardwire connection to the communications test set would be replaced by a microwave dielectric link. In a variant of these tests proposed by TRW the near-field antenna output itself would be monitored through a coupler connected to a microwave link.

In summary, if electrical isolation of the satellite is required, one must decouple it through its surroundings using a dielectric data link or possibly through inductively loaded cables. If the former route is chosen there is a possible need to develop data links and associated electronics including analog-to-digital converters and multiplexers. The link will have to survive in a tank environment but not necessarily function during this shot. There will be a problem in locating these links inside the satellite. Their exact nature and whether they will be provided by the individual user or by the facility will depend on the degree to which the data requirements of different types of

spacecraft and the test procedures of different manufacturers can be standardized. The simplest course from the point of view of the facility operator is to require the test group for each satellite to provide its own links. There is a certain rationale to this approach as the detailed requirements for each spacecraft are somewhat unique and best determined by the testing organization connected with the satellite development. On the other hand, a requirement to develop such a link represents an added cost to the program imposed because of the specialized nature of an SGEMP test. Therefore, such added cost will undoubtedly be resisted by the manufacturer and by the SPO. Presumably, if SXTF is built, test requirements would be written into the PRD and recommended test procedures, including provision for test points, will be incorporated in a Mil Spec for SGEMP tests in a manner analogous to those established for EMC and EMI testing.

4.2.2.2 **Control and Monitoring of Pulsed Power Sources.** The charging, timing, and firing techniques for pulse power machines are primarily the province of the source builders. In the past, only a relatively few modules needed to be fired simultaneously (four each in CASINO and AURORA). Because the other parts of the facility to which the sources are interfaced was relatively simple they could be developed essentially independently without worrying too much about how the pieces fit together except for three areas:

1. Development of an overall facility and shielding scheme.
2. Providing timing spigots from the machine for triggering experiments.
3. Providing interlocks to prevent charging and firing of the machine with personnel near high voltage and radiation sources.

In developing the SXTF facility much more attention will have to be paid to the interconnections between the photon sources and other parts of the facility for the following reasons:

1. The need for closely controlled timing to obtain proper phasing of the large number of sources involved will make required control and monitoring techniques correspondingly more complicated. As part of an overall facility design it will be desirable to investigate whether common data transmission and recording schemes can be developed not only for facility controls but also for machine controls. Another area in which standardization may be applied

is timing circuits. It may be possible to utilize the same timing instrumentation for both the radiation sources and the triggering and fiduciary schemes developed for recording SGEMP data (Ref 9). Sheer numbers will probably require modularization of data monitoring with overall processing and display controlled by one or more computers. It is likely that charging, timing, and firing will also be under partial computer control although probably with one or more operators integrated in the firing sequence loop (see Section 3.3 on Facility Controls and Test Panels).

2. The proposed test of the SGEMP response of a functioning satellite is considerably more complicated than anything attempted to date. Carrying out these tests will involve close coordination in the operation of the photon sources, facility environment, and AGE.

3. Each major instrumentation subsystem is likely to be developed separately on a different time schedule and to some degree tested independently of the others. It is important to have confidence that when the individual systems are connected together that they play together. In this regard unanticipated ground loops can be serious. The developers of the LASL 10 kJ eight-beam CO_2 laser system told us that when the diagnostic instrumentation was connected to the rest of the system, ground loop problems kept it from functioning for several months.

In developing the timing and firing controls and data monitoring schemes for the MBS and PRS, consideration should be given to the use of fiber optic links for the following reasons:

1. Very high voltages and currents must be monitored in charging and firing the capacitor banks, marx generators, transmission lines, and diodes. Therefore it is desirable to provide isolation between sources and recording equipment, especially facility computers, in case of breakdowns. This can be done with fiber optic links or with optical isolators.

2. Large EMI signals will be generated when the sources are fired. Therefore, decreasing the number of conductors running from the sources to other parts of the facility will lessen noise propagation.

3. It will be important to maintain isolation between the experimental chamber, data room, control rooms, and the AGE. One means of doing this is by interconnecting them with dielectric data and control links.

Therefore, we feel that the solutions developed to provide dielectric isolation, noise suppression, and grounding and shielding by the laser fusion community, particularly at the LASL ANTARES facility bear close study. They have had to solve problems in terms of noise suppression, grounding and shielding in an environment very similar to that which probably will be found at SXTF.

4.2.2.3 Grounding and Shielding. During the course of the SXTF program several general discussions of grounding and shielding schemes for the system have been presented (Refs 10,21). These discussions have had several elements in common in regard to a facility grounding and shielding design. These are:

1. Provision for a common facility ground plane comprised of a wire mesh embedded in the facility concrete foundation and tied at many points to earth ground. While not mentioned in either discussion, the effectiveness of such a ground plane will be considerably enhanced if the foundation is made from conducting concrete which is available commercially or may be part of the repertoire of the Waterways Experimental Station.

2. Providing a Faraday cage for each of the major subsystem components, namely the photon sources, the instrumentation and facility control screen rooms, and the AGE area in order to keep source noise from coupling into data and control rooms.

In addition the Jaycor report (Ref 10) discusses a topological philosophy of grounding whose thrust is to provide a multiple shield, multiple ground point system to keep noise signals from coupling into cables or into penetrations through which cables are brought into the Faraday cages. A clear discussion of this philosophy can be found in Vance (Ref 22). This treatment, predicated on the use of hardwire connections between major facility areas, makes extensive use of double shielding techniques such as cables within conduits, especially machined sleeves for cable penetrations which are carefully sealed with conductive epoxy or crimpable foils, and multiple ground points to minimize the paths along which energy can couple into cables. The design techniques discussed in References 10,21, and 22 have been worked out and validated in several UGT's and in the design of some large flash x-ray machines. It has been demonstrated

that when consistently applied their use ensures a relatively noise-free system. However, the advent of optoelectronic technology provides an alternate means of developing grounding schemes which have all the advantages of the presently used systems while providing considerably more flexibility in facility design and operation (Refs 4,5).

The basic element of such grounding schemes is to replace hardwire connections and the resultant relatively elaborate shield within shield penetration schemes with somewhat simpler shielding schemes for subsystems which are connected together with fiber optic links. It is claimed that the advantage of using fiber optics in developing a shielding system include:

1. No noise is coupled into fiber optic links. One need not pay as much attention to shielding between subsystems. Penetrations for the entrance of fiber optic links into Faraday cages are easier to construct. Of course, electronics and hardwire connections must still be shielded. However, these cable runs can be kept relatively short and inside the Faraday shield.

2. High voltage isolation and protection of primary subsystem facility instrumentation is automatically provided. This is a definite advantage for SXTF as many circuits and cable runs must be operated near systems such as pulsed power and backscatter control grids which will be operated at high potentials.

3. Major subsystems are electrically isolated so they can be developed and brought on line separately. The risk is minimized that when connected together, unforeseen noise and ground loop problems will hamper facility operation.

A detailed grounding and shielding plan as opposed to a conceptual design (as philosophical statements on how to do it) requires further definition in the following areas:

1. Identification of the frequency and amplitude of the major facility noise sources.

2. Definition of facility layout—if the present Jaycor floor plan is accepted, then this has been done.

3. Determination of instrumentation sensitivities to determine how much noise suppression through shielding is required.

Only after these topics have been addressed in more detail should a final decision on a facility shielding, grounding, and penetration plan be adopted. It is not claimed that fiber optic systems will permit the development of a cheaper, superior grounding and shielding scheme. However, present shielding practice, while effective, is based on old technology. The advantages of using fiber optic links in developing a grounding and shielding plan should be investigated before that plan is "fixed in concrete", especially if considered as part of an overall facility data transmission scheme.

4.3 HIGH FREQUENCY FIBER OPTIC DATA LINKS

4.3.1 Introduction

This section assesses the current and projected state of the art of high frequency fiber optic data links. Particular emphasis is placed on links that would be useful in SGEMP test facilities to transmit data from the object under test to the data screen room. Fiber optic data links have two primary advantages over metallic conductor links in this application. First, the fibers are immune to electromagnetic pickup and thus would be significantly less subject to noise pickup caused by the test pulse. Second, the dielectric nature of the fibers means that they would not significantly disturb the electromagnetic field distribution in the test chamber. In fact, these two advantages make fiber optic data links highly preferred for this application.

A very similar application is data transmission in EMP tests. Here again, the advantages of fiber optics are very important. As a consequence, several different systems have already been designed, fabricated, and used in EMP simulator experiments. These systems generally have many of the attributes, including high frequency capability required of SGEMP links. Therefore, some of these links have been used for SGEMP data transmission. The capabilities and inadequacies of the existing EMP/SGEMP links will be examined subsequently. Current programs aimed at improving link operation in an SGEMP environment are discussed and the resulting capabilities of the modified links noted.

The electromagnetic immunity of fiber optics is useful in other applications where significant electromagnetic interference exists. In some cases, the data transmission requirements are fast enough that the links could potentially be usable in EMP/SGEMP testing as well. Specific areas where this has already occurred are in laser fusion facilities and underground nuclear tests. Both of these applications require nanosecond-type speeds and transmission in the presence of large electromagnetic interference.

The possible application of these links, or at least the technology or concepts used in these links, to EMP/SGEMP data links will be examined later in this section.

Before discussing the links that currently exist, the requirements that an EMP/SGEMP data link must meet will be identified. Particular emphasis is placed on radiation tolerance which is not required in many applications such as EMP testing. It is in that area that the capabilities of links used in laser fusion facilities or underground tests are particularly pertinent, and techniques developed for these links may be particularly applicable to links to be used in SGEMP tests.

The final portion of this section examines potentially applicable technologies that are not currently being applied to the problem and projected advances in the state of the art, and considers how these might augment link capabilities. The best performance of a fiber optics link is then predicted and matched with the requirements.

4.3.2 Requirements on an SGEMP Data Link

There are a number of requirements that must be met by SGEMP data link. The ones that will be discussed here are those that are either unique to the SGEMP link or are difficult for a fiber optic link to achieve. The radiation hardness requirements are treated separately from the nonradiation ones, although the solutions must take both into account.

4.3.2.1 Nonradiation Requirements. Most of the special requirements that use in SGEMP testing imposes on a fiber optic data link result from the need for high-frequency, analog data transmission. Other requirements are imposed by the special test environment in which the link must operate.

A primary requirement of the link is that it will be wideband or high frequency so that it can faithfully reproduce the data which measures response to the test object. The rate of change of the fastest signals that must be recorded is conjectured to be equivalent to a risetime of about 1 nsec. This would require a system bandwidth in excess of 350 MHz. It is probably desirable to have a bandwidth of about 500 MHz because the 1 nsec risetime is only an estimate. Bandwidths on the order of 200 MHz might be marginally acceptable in some instances, especially if other system characteristics were improved by the tradeoff.

The signals encountered could range from the 1 mV to the 1 kV range, which would require a system range of 120 dB. However, it is highly unlikely that anything approaching this could be achieved without external control, given the quality of light

sources currently available, or those which may be available in the near future. Thus, the requisite range must be achieved by the use of attenuators or gain control coupled with a dynamic range that is sufficient for accurate signal reproduction. A minimum dynamic range to allow a good reproduction of any given signal would be on the order of 40 dB. This would require an adjustable attenuation range of 80 dB. The adjustment steps should be 5 dB or less so that essentially the entire 40 dB dynamic range would be available at any signal level within the 120 dB system range.

One of the requirements that electrical isolation of objects in the test chamber places on the transmitter is that the power be internally supplied. This requirement dictates a battery powered transmitter. Since frequent battery changes would be highly undesirable because of repeated tank evacuation, long battery life is a necessity. Pumpdown time in the test chambers could be eight to ten hours or more, so daily battery changes are unacceptable. Operation for at least a week would generally be acceptable. Conservation of batteries by shutting them down between shots or recharging of batteries, perhaps via an umbilical that could be connected between shots and disconnected for shots, could be used to increase battery life.

Another requirement on the transmitter is that it be as small a size as possible so it produces a minimum perturbation of the electromagnetic field when placed in the test object, particularly with the number of transmitters that are liable to be required for SGEMP tests. Further, many of the locations in the satellite where it may be necessary to locate a transmitter require small size objects. A desirable goal would be a transmitter size of about two inches on a side, or perhaps a three inch square by one inch thick unit.

Another requirement is for a fiber cable length of at least 25 meters to get beyond the test tank wall, and probably 50 meters or more so that transmission to a reasonable location in the data room could be achieved. Transmission over this distance must be achievable without degrading the system bandwidth or signal-to-noise ratio.

Calibration of the link will also be required. Since the calibration signals must be injected as close to the input of the link as possible, the calibration source will have to be located in the transmitter. Ideally, the calibration signal levels should cover the entire range that might be encountered. However, an adjustable calibration that ranges from mV to kV is not likely, so a fixed calibration signal injected just beyond the attenuator is required. The attenuator calibration must then be accepted and the setting checked by other means. The calibration signal should be bipolar so that both positive and negative system response can be examined. A ramp signal to check the

gain at all signal levels is the best kind of signal. The maximum levels (positive and negative) of such a ramp signal should extend beyond the linear range of the system into saturation so the useful range can be determined.

Because the transmitter must be electrically isolated, any command or control functions must be achieved using another fiber optic link. These functions would include attenuator setting, turning power ON or OFF, triggering the calibration signal, etc. This control link need not be an analog link because these functions can be readily implemented digitally. Nor need it be high frequency since it does not have to operate on a time scale to reproduce the pulse. Further, all the functions can be performed between shots when there is ample time.

In the control link, it is the receiver and not the transmitter that is in the test chamber. As a result, those requirements imposed on the high frequency link transmitter that come about because of the location must also be met by the control link receiver. These include internal power (use of the same power source as the transmitter is likely) and small size.

4.3.2.2 Radiation Requirements. SGEMP testing is done by exposing the test object to ionizing radiation. Therefore, the fiber optic data link must be capable of operating through and surviving this environment. This section considers the radiation levels to which the link will be exposed.

The test facility in which the data link will be used will contain an x-ray source. The link will be exposed to an ionizing radiation pulse through which it must operate. It must also survive the total dose that would be accumulated from exposure to a number of shots.

The x-ray source considered in this assessment generates two types of output. A plasma radiator provides the low energy portion of the spectrum and a bremsstrahlung source provides the high energy portion of the spectrum. None of the components in the fiber optic link will be directly exposed to the radiation, and some will be shielded by a significant amount of shielding. Even the fiber cable, sections of which will not be shielded by the test object, will be jacketed by enough material to provide some shielding. Figure 2 shows the dose deposited behind aluminum shielding for various energy blackbody sources. The shield thicknesses shown are typical of the minimum that would exist. As can be seen, the dose from the low energy photons ($E_{bb} \leqslant 3$ keV) rapidly becomes negligible compared to that from the higher energy photons, so the low energy contribution to the total can generally be ignored. Even if it cannot be, it is at

most a correction on the order of a factor of two, and uncertainties in machine output level and shielding thickness are at least this great at present. Therefore, the contribution to the total dose from the low energy photons from the exploding wire source will be ignored. Charging of the fiber cable by the low energy photons is also unlikely to be important because (1) the radiation source is photons so they will not directly deposit charge, (2) there is no high-Z, low-Z interface to enhance differential charging from secondary emission, and (3) there is no nearby metal to serve as a ground plane for a discharge. Further, the time between shots should be more than sufficient to allow relaxation of any charge buildup, so cumulative effects should not occur.

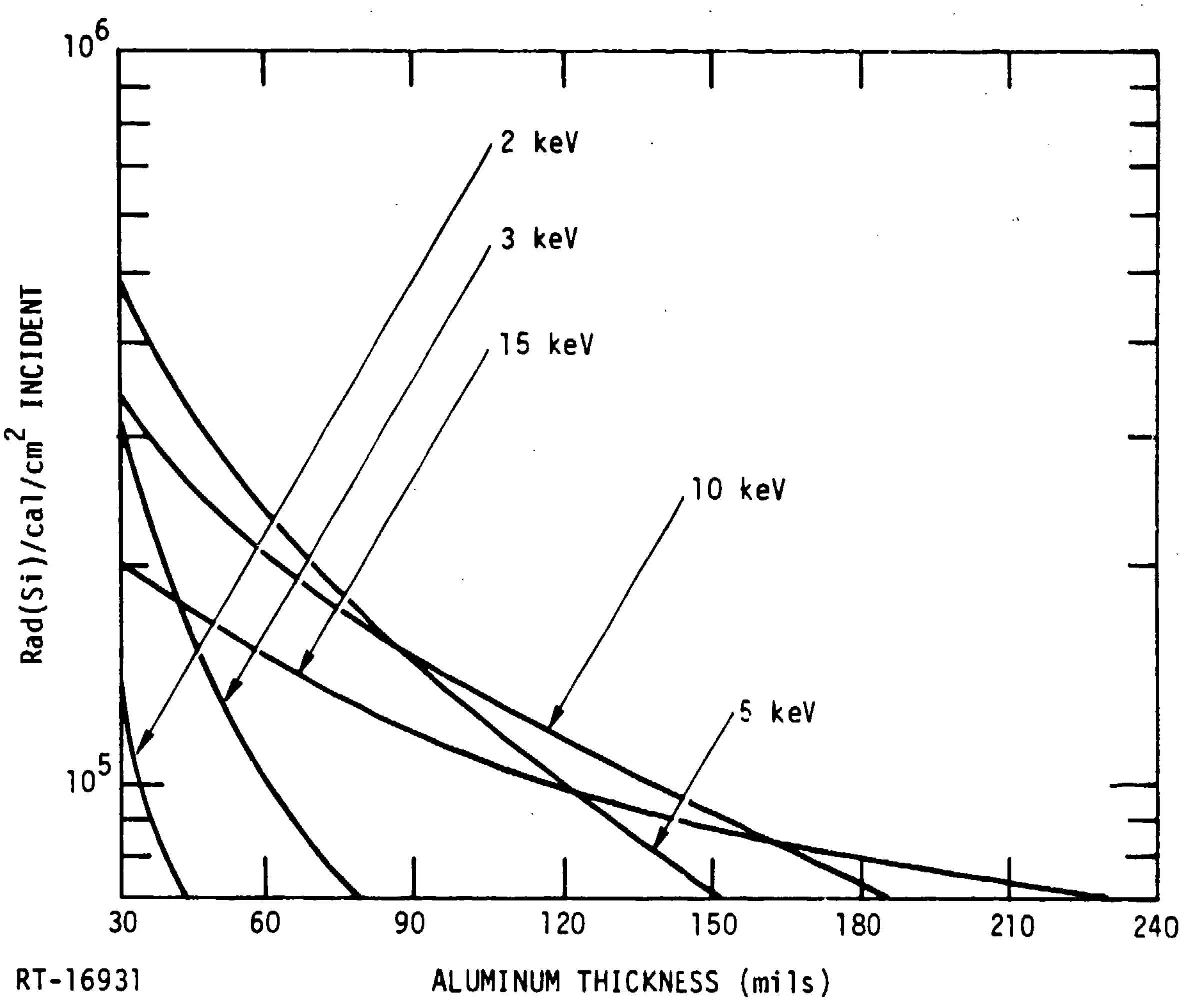

Figure 2. Dose deposited by various energy x-ray sources behind aluminum shielding.

An estimate of the dose to the link produced by the high-energy portion of the source must now be determined. For this purpose, the radiation is considered to be similar to the output of the SPIRE Pulse 6000 x-ray machine. This is taken to be similar to a blackbody in the range of 10 to 25 keV, depending on charging voltage and details of the anode/cathode geometry.

The transmitter will be inside a housing and perhaps behind the batteries which will provide some shielding. In addition, the transmitter may be shielded by parts of the test object itself. The dose per pulse that could strike transmitter components could be as high as 100 rad(Si) depending on the fluence attained. Because the radiation remaining after this shielding is high energy and quite penetrating, the amount of shielding that would be required to significantly reduce this dose from this component would be relatively large.

Estimating the fiber dose is more difficult because some of the cable will be at approximately the same location as the transmitter and thus would be shielded by the transmitter and probably the test object, while other portions of the cable may be directly exposed to the beam but at a distance that is likely to be farther from the source than the transmitter. Although the source will irradiate a large volume, the exposure level will certainly decrease with distance, and this will counter the effect of the lessened shielding. It may even be possible to route the cable so that the entire length is shielded by the test object. (Other considerations, such as distance involved and a radiation hardening technique to be mentioned subsequently, may require a tradeoff analysis to determine if this is desirable.) Considering all this, the dose absorbed by the fibers is estimated for purposes of this assessment as the same 100 rad(Si) per pulse maximum as was estimated for the transmitter electronics. This level will certainly exist near the transmitter, and could quite possibly exist at all points on the fiber. The exposure room, as currently designed, has a maximum dimension on the order of 30 meters, which means that at least 15 meters of fiber cable could be exposed before passing out of the exposure room.

In normal link operation, the receiver would be outside the exposure tank and thus would not be subject to exposure. Thus, there is no radiation hardening requirement that need be leveled on the receiver.

The pulse width of most flash x-ray machines is on the order of 50 nsec. Assuming this and using the 100 rad(Si) per pulse maximum dose gives a maximum dose rate on the order of 2×10^9 rad(Si)/sec. This and the 100 rad(Si) dose are the maximum environment levels for a single pulse which must be considered in link evaluation and

design. The link must operate through these radiation levels with no change in capabilities, either transiently or permanently.

It is also desirable that the link be usable for multiple pulses without refurbishing. A reasonable minimum requirement would be survival for 100 of the maximum pulses [or 10^4 rad(Si)] with a desired goal being perhaps 1000 of the maximum pulses [or 10^5 rad(Si)].

The control link, in particular the receiver and fiber portion, must also survive these ionization pulse levels. It need not operate through the pulse, but it must be able to function after the pulse and survive the multiple pulses. Also, it must not produce a false command as a result of the pulse. The radiation tolerance requirements on the control link are relatively easily met and will not be considered further in this assessment.

Consideration is also being given to including a source in the test facility which would simulate the space electron environment. One component that might be simulated by this source could be relatively high energy ($\sim$1 meV or higher) electrons at a steady flux of up to 10^9 e/cm^2-sec. One-MeV electrons would have a range on the order of 0.5 g/cm^2 and higher energy electrons even more, so relatively unshielded components (such as directly exposed fiber cable) could receive significant exposure while the exposure of well-shielded components (such as the transmitter) would likely be insignificant. The dose rate of the exposed components could thus be as high as 25 rad(Si)/sec. The link must operate properly while exposed to this dose rate. This electron source would be used primarily for spacecraft charging experiments. To achieve the necessary fluence for charging equilibrium to simulate post-burst effects, about a 30-minute exposure would be required. This means that a total dose of about 5×10^4 rad(Si) could be accumulated by exposed components. It would be desirable that the link survive several (perhaps 20) of these exposures without refurbishing. Thus, a total dose requirement goal of 10^6 rad(Si) exists for exposed components.

The radiation tolerance goals [one pulse: 100 rad(Si)/pulse, 2×10^9 rad(Si)/sec; multiple pulse total dose: 10^5 rad(Si); space electron simulation: 10^9 e/cm^2-sec or 25 rad(Si)/sec, 5×10^4 rad(Si) per exposure, 10^6 rad(Si) total dose] may be higher than will actually be achieved; however, it is potentially possible to achieve them so link design should strive to meet them.

4.3.3 Currently Available Links

4.3.3.1 **SGEMP/EMP Links.** There are several fiber optic links in existence which have some application to the high-frequency, analog data link problem. The most directly applicable are the links built by HDL (Refs 18,23) for SGEMP experiments and by Lockheed (Ref 24) which were originally designed for data transmission in EMP tests. These two links are generally similar, although there are some important differences between them. Both transmitters employ a GaAℓAs laser diode manufactured by Laser Diode and transmission is over a germania-doped silica graded-index fiber cable (manufactured by Siecor for the Lockheed link and Corning for the HDL link). The bandwidths (expected to be 400 MHz for the HDL link, 650 MHz for the Lockheed link) are adequate for the experimental requirements while the dynamic range (claimed to be up to 35 dB in both cases but less in practice, at least for the HDL link) is marginal at best. The improvement of the dynamic range is one of the major areas of improvement being addressed in development programs being undertaken by HDL for DNA and Lockheed for AFWL. Both the speed and dynamic range are controlled by the laser diode, and the somewhat better operating characteristics of the Lockheed link were achieved primarily by greater selectivity in diode choice.

Because of the narrow dynamic range, both receivers have remotely controllable attenuators in the transmitter. The HDL link has one covering a 0 to 45 dB range which is not fully adequate, while that of the Lockheed link encompasses a more adequate 0 to 93 dB range. Both are settable in 3 dB steps. Both links were designed so that the attenuators would not be upset (change setting) by the radiation pulse. A difference between them is that after the initial command, the HDL link requires continuous power to retain the attenuator setting while the Lockheed link does not, resulting in a power savings for the latter.

The current HDL attenuator design is very susceptible to IEMP effects because of the cavities it contains. Since radiation tolerance was not considered in the Lockheed design, it is likely that it also is susceptible to IEMP effects. Since the attenuator is on the input of the transmitter, transients in it will be very important in determining the radiation tolerance of the transmitter.

Both transmitter units are self-contained and remotely controlled by a second fiber optic link. Batteries are used to supply the power. The HDL link uses rechargeable NiCd batteries. These batteries have only about a two-hour continuous operating life, and are also somewhat bulky, taking up about one-third of the transmitter package. However, they do provide some radiation shielding for the rest of

the transmitter. The short battery life requires that the batteries be turned off between shots. The Lockheed link uses lithium batteries which are much smaller while having about a 40-hour continuous operating life. Therefore, they are left on between shots which keeps the laser diode biased above threshold and decreases the possibility of troubles from turn-on transients. The increased lifetime is an inherent property of lithium batteries. Their drawback is cost and the fact that they are not rechargeable. Thus, they must be replaced when they are run down, which adds to the expense. However, compared to the overall expense of a test, battery expense is likely to be negligible.

The HDL transmitters have a physical size of 3-1/2 inches by 3-3/4 inches by 8 inches, while the Lockheed link is somewhat smaller because of the smaller batteries. Both transmitters are larger than is desirable for the application.

Both links have a differential input into the first stage (the attenuator), and then are single ended thereafter. The HDL link uses a transformer to couple into the attenuator. Whether the Lockheed link does or does not was not discussed.

The HDL receiver uses an avalanche photodiode while the Lockheed link uses a PIN photodiode. In general, the gain available in an avalanche photodiode allows a receiver with a higher signal-to-noise ratio to be constructed. This is because the controlling receiver noise is usually the preamp noise and not the photodiode noise. Therefore, gain in the photodiode increases the signal-to-noise ratio until the diode noise becomes comparable to the preamp noise. However, in this application, the laser diode is biased above threshold so that it operates in its linear region, and thus it is emitting a background light. The noise on this light output and also the shot noise that the light produces in detectors are the controlling noise levels in the link. As a result, there is no signal-to-noise advantage to an avalanche photodiode in this application.

Another potential advantage of the avalanche photodiode is speed. However, both PIN and avalanche photodiodes are faster than the laser diode in the transmitter, so this potential advantage was not realized either.

In both links, calibration signals are injected just beyond the attenuator. These signals are step functions, with the HDL link signal being unipolar and the Lockheed link signal being bipolar. Both have only one value of about 10 mV. Thus, neither provides an attenuator calibration or a calibration of the entire dynamic range of the laser diode, and the HDL link does not even provide a calibration of negative polarity signals.

Radiation hardening (for ionizing radiation) considered in designing the original version of the HDL link was not for the original Lockheed link. One of the major steps

taken by HDL was to choose a radiation hard fiber. Lockheed chose essentially the same graded-index fiber because of its low loss (allowing sufficient fiber length) and low pulse dispersion (retaining high bandwidth with the necessary length). Therefore, the radiation tolerance of the fiber is the same in both cases.

Of the fibers that fall in the radiation-tolerant class, the germania core fibers chosen are perhaps the most radiation sensitive. A peak transient absorption of about 6×10^{-3} dB/m-rad(Si) is produced by exposure to ionization (Ref 25). Thus, a pulse on the order of 0.5 rad(Si) would begin degrading the signal level, where the worst-case exposure of 100 rad(Si) would produce a degradation of about 10 dB. Thus, the currently used fibers do not display sufficient hardness for operation in the required pulsed environment.

The multiple pulse requirement of 10^5 rad(Si) should be achievable with the fibers being used because the permanent degradation produced should be no more than a few dB (Ref 25). Since the degradation produced by any one pulse of 100 rad(Si) or less should die effectively away to a permanent value in a few minutes, calibration of the link at each shot should allow the user to correct for these permanent changes.

Another important step taken to harden the HDL link but not considered for the Lockheed link is the use of a narrowband optical filter between the fiber and the detector. This eliminates the out-of-band transient luminescence during exposure, and cuts down this noise source significantly. The maximum luminescence from the fibers will be on the order of 3 μW which would likely degrade the signal-to-noise ratio. There is some question as to whether this is truly luminescence (Ref 25), or is actually Cerenkov radiation (Ref 26). If it is Cerenkov in origin, orienting the fibers properly so as to minimize the launching of the directional Cerenkov light into the fiber could alleviate this potential problem. Choosing the optimum angle would involve a tradeoff between the direction where Cerenkov effects were maintained and the direction where the radiation was minimized. This might result in the choice of a direction where the test object would not shield the cable.

The steady-state electron flux exposure of the fibers could pose an even more serious problem than the pulse exposure. Steady-state irradiations (Refs 27,28) of fibers, including fibers similar to the ones used in the links, have shown that losses that would begin to affect link operation occur at a total dose of about 100 rad(Si), at least dose rates between 0.4 rad(Si)/sec and 300 rad(Si)/sec at the single exposure objective of 5×10^4 rad(Si), a 10 dB degradation would result, about one-third of which

is permanent. Thus, the currently used fibers do not have sufficient hardness for this environment either.

No special steps (beyond shielding) were taken to harden the transmitter. Photocurrents or noise currents could be produced in the attenuator or the first amplifier stage (assuming typical, high-frequency amplifiers) that will be amplified and would be sufficient to degrade link performance at 10^6 to 10^7 rad(Si)/sec. This again is well below the requirement. In fact, at the maximum 2×10^9 rad(Si)/sec, it may be possible to produce sufficient current to burn out the laser diode.

The ionization pulse will not directly drive the small-volume laser diode enough to degrade link performance.

The bottom line on link radiation tolerance is that neither the transmitter nor the fiber have sufficient radiation hardness to meet the potential requirements. This holds both for the HDL link for which hardening has been considered and even more so for the present version of the Lockheed link for which it has not been considered. It should be noted that both systems are currently undergoing redesign and hardening. The anticipated results of this are discussed subsequently.

4.3.3.2 Other Applications. Another area in which high-frequency data transmission using fiber optics is being considered or used is for diagnostics in laser fusion facilities. LASL (Ref 3) certainly and Lawrence Livermore Laboratory have built such links. Thus far, wideband fiber optic links have not been built, so the ones that exist are not directly applicable to SGEMP testing. The reason wideband fiber optics links have not been built is that this application does not require the complete absence of electrical cables, just their being of minimum length to minimize electromagnetic pickup. Thus, the current links bring the data from the exposure area to a location just outside the target area by hard wire. At this point, the high-frequency analog data is digitized on a wideband digitizer such as an R7912 where it is stored. After the pulse, the digital data is transmitted to the data room at a relatively low frequency over a serial fiber optic link. Thus, the fiber optic link need be neither high frequency nor analog, which is why it is not directly applicable to SGEMP test needs. However, the bandwidth of the overall system is more than adequate for SGEMP link needs, so that, if the means to meet all of the other SGEMP requirements could be found, the technique of digitizing the data and then transmitting it could be used. The primary need would be a high-speed digitizer and memory which is sufficiently radiation tolerant to allow it to be located in the test object and thus subjected to the radiation environment.

As the laser fusion fiber optic links are not directly exposed to ionizing radiation, no hardening techniques have been considered which can be applied to the SGEMP link problem. Fiber optic links for laser fusion diagnostics which have no hardwire link input, and thus where the transmitter is in the laser fusion exposure room, are being considered at least by Lawrence Livermore, but none apparently have been built or tested yet. If such links are successfully built, they would likely meet more stringent requirements (at least in the case of the planned NOVA facility at L^3) than are imposed by SGEMP tests, and thus would be directly usable in SGEMP tests. Therefore, progress in the area should be monitored. LASL has built high-frequency, analog fiber optic links for underground nuclear test diagnostics (Ref 29). These links use scintillators as the sensor. The radiation-induced light is coupled directly into the fiber, so problems with a laser diode transmitter are not encountered. The system bandwidth is primarily limited by the scintillator response time, although fiber dispersion in relatively long systems (>100 meters) also has an effect. The feature of these links that is directly applicable to SGEMP links stems from the fact that the fibers exposed to an ionizing radiation environment that is more severe than the SGEMP pulsed environment. Thus, the fiber selection criteria had to include radiation tolerance. The two types of fiber that they use are (1) a graded-index fiber (for long transmission length), and (2) a polymer-clad silica (PCS) fiber (for radiation tolerance). The graded-index fiber is probably similar to the fibers used in the HDL and Lockheed links and thus would have a similar radiation vulnerability. The PCS fiber is the most radiation resistant fiber currently produced. In an SGEMP data link using the fiber, it would require 10 rad(Si) or more in a pulse before the signal would change 1 percent. Therefore, these fibers are much closer to achieving the desired hardness than are the germania-doped fibers currently used in the HDL or Lockheed links, and the shielding that may be required is more feasible. Further, a single fiber of this type could be used successfully because it has a larger diameter. The Cerenkov radiation (or luminescence) from this single PCS fiber would be about the same as that from the seven-strand germania-doped fiber used in the HDL link. Thus, the potential vulnerability would remain within reason. The penalty paid for using PCS fiber is the length limitation imposed by the pulse dispersion of this step-index fiber.

Relatively wideband data links have been built using LEDs in the transmitters (Refs 30-32). The high-frequency limit of these links is in the 100 to 200 MHz range. In digital applications, rates as high as 500 Mb/s have been achieved because only the presence of signal and not faithful reproduction of the input is required. Hitachi at least makes 150 MHz LEDs (trading off optical output for speed), but link bandwidths

above 100 MHz are generally achieved by a speed-up network or compensation in the drive circuitry. The highest currently achievable bandwidths are borderline for SGEMP test use, although they may be adequate for diagnostics. Since the speed of these LED-based links is approaching the minimum required for SXTF use, advances in LED technology could push these systems into a useful region. This would allow some of the advantages of LEDs to be incorporated into the link.

One of the major problem areas where LEDs might provide an advantage is a greater linear range for the links. Although LEDs have a greater linear range as a device than laser diodes, this cannot be directly transferred into added link range in the application where bipolar operation is required. To achieve this with unipolar sources such as LEDs and laser diodes, the devices must be biased to the middle of their operating range. The noise in the link, which sets the minimum detectable, is set by this dc light level. Either the noise in the light source itself or the shot noise that the light produces in the detector controls the noise. The maximum signal achievable would be equal to the dc level, and this occurs only if the minimum signal in the linear range is negligible. Assuming that detector shot noise dominates the light source noise, the minimum signal is negligible, with amplifier current assumed to be 3×10^{-7} amps (Ref 34), and the minimum detectable signal is at a signal-to-noise ratio of 1.0, the current quoted link linear range of about 40 dB could be achieved with as little as 60 μW of power on the detector. It is actually possible to achieve a power level on the detector where a range approaching 60 dB is predicted. This is not achieved in the laser diode links probably because the light output from the laser is itself noisy and significantly increases the minimum detectable signal. It is here that LEDs may provide an advantage; LEDs are more stable than laser diodes, and this could well produce a lower noise and wider linear range.

Other LED advantages are long-term stability, temperature stability, lower dc bias power requirement, and higher yield of acceptable devices. These advantages would result in a transmitter that is simpler, easier to use, more reliable, and smaller.

None of the currently available fiber optic links developed for any of these other applications are directly applicable to SGEMP testing needs. However, some of the technology employed can be applied, and future developments could make the links more desirable.

4.3.4 Anticipated Improvements

4.3.4.1 Improvements That are Being or Could be Implemented Now. Both HDL and Lockheed are currently addressing improving their links. One of the major problems that HDL is attempting to solve is dynamic range. The primary effort has been to find a laser diode with improved properties, and the candidate at present is one made by Nippon Electric. As well as providing increased dynamic range, it is hoped that the new diode will provide increased bandwidth, greater stability, and greater yield of useful devices. Yield is important because adequate performance of the current links depends on selection of devices with much better than average performance for the types employed. Improved radiation tolerance is being addressed by attempting to repackage the transmitter in a smaller package (fill the voids) so it is less susceptible to IEMP effects and replacing the IEMP sensitive attenuator with one that is less vulnerable. These changes will make the transmitter less vulnerable than it currently is, but they will not affect the vulnerability of the amplifiers to pulse transients, so the transmitter will still not have sufficient radiation tolerance to meet the requirements. Further, although the size decrease is a step toward the small-size goal, it is not likely to result in transmitters that actually achieve the goal.

HDL is planning to use the same type cable, but this does not necessarily mean that the radiation vulnerability will remain the same. The current Siecor (Corning) graded-index fibers are doped with both germanium and phosphorus. These newer fibers have been found to have about an order of magnitude less vulnerable to pulse transients (Refs 26-28), making them nearly as hard as the best PCS fibers. Measurable effects on link performance would begin at about 5 rad(Si) and would be about 3 dB at the maximum dose of 100 rad(Si). Thus, simply replacing the fibers with the newer ones of the same type would improve the link radiation tolerance, although sufficient hardness for the application would not exist.

One other improvement that HDL is working on is a lower power requirement in the data link transmitters and the control link receiver. This would translate primarily into longer battery life.

Lockheed's improvement efforts are aimed at addressing radiation tolerance of the link. They are working on repackaging the existing transmitter into a smaller and less IEMP vulnerable package. Again, this is not likely to fully achieve the small-size goal. Shielding to improve ionizing radiation hardness is also being considered. It is likely that the improved Lockheed link will be very similar to the improved HDL link.

To determine what can be accomplished with current technology, one can combine the desired properties of the various current links into one link. The transmitter from the Lockheed link, with its dynamic range, high-frequency capability and long-lived batteries, could be combined with the PCS fibers used in the LASL underground test link, with their radiation tolerance. Adding the shielding (such as used in the HDL link) would give the best combination from already tested units. There would still be problems with dynamic range and size in the transmitter radiation tolerance in the transmitter and fiber cable (even with PCS fibers), and the step-index PCS fibers would limit the length that a high-frequency link could be used because of mode dispersion. Changing to the Ge- and P-doped graded-index fibers would allow longer length links with nearly the hardness of PCS systems to be developed. However, this would solve only one of the problems and leave size, dynamic range, and radiation tolerance insufficient for the application. These areas, as well as a bipolar ramp calibration signal, would still need improvement.

4.3.4.2 <u>Future Advances in Technology</u>. Maeda et al. of Hitachi have reported (Ref 35) measurements of the performance of a buried heterostructure laser that has shown a flat frequency response out to 1300 MHz and which is claimed to be flat to 2000 MHz. The threshold current of this device is quite low (21 mA), which would result in significant power savings. The linearity of the laser was not discussed in the paper, but it did have very low second-order harmonic generation (-52 dB) even with a modulation index of 0.4. Thus, it potentially has a good linear dynamic range. If its dynamic range is sufficient, it certainly is a component to be considered for a high-frequency data link because of the additional speed it possesses over the currently used components. Whether this laser would be better than the new Nippon laser being used by HDL or not remains a question for testing to show.

Since the modulated light source presents one of the major problem areas in the SGEMP link, one means of alleviating the problem would be to use a dc source and another transducer. One promising candidate that is currently being developed is a GaP acousto-optic modulator. Devices have been reported (Ref 36) with a measured risetime of 3 nsec, and this was thought to be measurement electronics limited and that the device had actually about a 1 nsec risetime. Another type of device that might be applicable is the Fabry-Perot resonator (Ref 37). Devices with switching times on the order of 1 nsec have been reported. These devices can be used as linear amplifiers as well as for digital applications. In both of these cases, the speed of the devices is

adequate for use in SGEMP data links. These are new devices, and their linearity as well as other properties has not been addressed. However, the area will bear watching because use of these devices may avoid many of the problems presented by laser diodes.

One of the major problems with the existing links is dynamic range, so this is an important area to address. This is not only true because of the desire for better signal reproduction, but also indirectly for radiation tolerance. the light source (or whatever transducer) has a larger dynamic range, less attenuation and amplification will be required in front of it. Th·· could well mean smaller or few components, which would result in less ionization-induced noise. Recently, several techniques for linearizing transmitters for analog fiber optic systems have been identified (Ref 38). These were complementary distortion, negative feedback, phase shift modulation, feed forward, and quasi-feed forward compensation. These involved electronic compensation of known distortion or monitoring the light output of either the same or another ·tical source and compensating for nonlinearities either with the source drive .t or adding light from a second source. Achievement of 40 dB improvement has been found using these techniques. The applicability of these techniques to the high frequency links under considera ion should be examined because they promise the potential of greatly improved link capability.

Since LEDs have potentially a greater linear range than laser diode, in applications where this is important, it may be better to use LED systems and give up some bandwidth. As LED technology advances, faster devices more applicable to the needs of SGEMP data links may be produced, and these could be incorporated. Further, analytical prediction (Ref 32) says that a LED transmitter bandwidth of 700 MHz can be achieved using a speed-up network and resonant peaking (the complementary distortion techniques for linearization mentioned previously). Although this has not been achieved in practice, improved circuit design and/or possible application of other linearization techniques could improve the LED frequency response enough that it will be sufficient for SGEMP link use. Thus, it may be possible to take advantage of greater LED while paying little or no significant bandwidth penalty.

4.3.3.4 <u>Areas That Must be Addressed</u>. The dynamic range of the input transducer (currently a light source) is one area where major improvement is needed. Perhaps some of the new laser diodes, or perhaps one of the developing electro-optical components, will be adequate. However, none are demonstrably so now, and thus this is an area to address.

Another area that will have to be addressed and improvements made is the transient response of the transmitter to the ionization pulse. Shielding could be used to lower the dose rate to which the transmitter would be exposed. However, the photons involved are high energy, so the shielding required may be too much considering the minimum size requirement. (To achieve a two-order-of-magnitude reduction that may be needed, a thickness of about four inches of lead would be required because of the penetrating ability of the higher energy portion of the x-ray spectrum.) Therefore, design changes should certainly be considered. One technique would be to balance each amplifier or oth-· photocurrent source with a reverse-biased diode so that photocurrent cancellation occurs. The tolerances required would be quite tight, especially at the first amplification stage where even a 0.1 percent mismatch may be too great. Added linearity, which would lower the required amplification, would ease this tolerance requirement. A second technique would be to actually switch amplifiers out of the circuit rather than using an attenuator to achieve the desired dynamic range. At the higher dose rates, all amplifiers would probably have to be completely removed from the circuit because even the unamplified photocurrents could be too large. This is potentially feasible because the test object signals available at these high dose rates are likely to be large enough to drive the laser directly. The difficulty with this technique is implementing the switching functions, without degrading the performance of the amplifiers (for example by introducing instabilities). In fact, if the input signals are sufficiently large, and of predictable magnitude, it may be possible to eliminate the amplifiers entirely. A system of this type is going to be used on the SGEMP experiment in the Diablo Hawk UGT. It is claimed that this system, based on the Lockheed design, performed satisfactorily at dose rates above 10^9 rads(Si)/sec. Although these techniques would be difficult to successfully implement, one of them, or some other technique, will likely be required if the transmitter is to be usable at the required dose rate.

The radiation tolerance of the fibers is another area in which improvement is necessary. Sufficient prompt pulse hardness does not exist in any currently available cable, although some come close. Future fiber cable advances may achieve the necessary improvement. One interesting approach is prior irradiation of the cables. It has been found (Ref 39) that the radiation response of some fibers is significantly decreased by prior exposure to radiation to levels for which no permanent degradation has been observed. It thus may be possible to produce harder cables by exposing them to radiation before they are used in a link. This is definitely an area in which research

is needed. The achievement of fibers that are harder to prompt-pulse effects is desirable over the alternative of shielding because the amount of shielding required to decrease the higher energy portion of the x-ray radiation to an acceptable level could be as much as the equivalent of one inch of lead. This would be difficult to accomplish using a dielectric material which would be required for isolation and lack of E-M field distortion achieved by using fiber optics.

The tolerance of the fibers to the simulated trapped electron ($\sim$1 MeV) steady-state flux is nowhere near what is required. It is unlikely that improved fibers will be able to achieve the necessary tolerance. Therefore, shielding of the fibers will be necessary. Shielding for the electrons is more possible than the x-rays because the range of the electrons is much less than that of the higher energy portion of the x-ray spectrum. It would be possible to achieve sufficient shielding by routing the fibers so they are always shadowed by the test object, or by placing them in a cable with about 1.0 g/cm^2 or so shielding. This shielding would also help alleviate the effects of the prompt pulse. The shielding would have to be dielectric in nature so as to retain the advantage of the nonmetallic fiber optic cable.

Another area in which development is needed is in improving the calibration signal so that the gain of a link over the entire range and not just at one point can be determined.

The conclusion of all this is that there is still development required before a high-frequency fiber optic link can meet all of the requirements imposed on an EMP/ SGEMP data link. The primary areas requiring improvement are transmitter and fiber cable radiation hardness and linear dynamic range. Bandwidth of the transmitter is also a consideration, although more than adequate behavior in this area is currently achievable. It may be, however, that some sacrificing of bandwidth (by using LEDs) may result in achieving the desired properties in the other two areas. There are several promising areas which are being or should be examined which hold the promise of achieving all the goals, and these should be pursued.

Thus, while links built using current state-of-the-art may not be capable of achieving the desired goals, they are close. Even without completely meeting all the goals, fiber optic links driven by laser diodes (or possibly LEDs) are still the preferred choice because of the dielectric isolation they offer. Further advancements projected for the near future indicate the possibility of satisfactorily meeting all the goals.

4.4 DATA RECORDING AND DIGITIZATION

4.4.1 Data Recording in SXTF

A large amount of data must be collected and processed during the operation of the facility. In order to make this data available to operators and users in a meaningful format and in a timely fashion digitization is mandated. To what degree and how data will be displayed should be determined as part of the initial conceptual design which identifies the data to be measured, its type, and importance. This information will impact the degree to which data and control functions are standardized and computerized. In this exercise, consideration should be given to cost per channel, advantage in improving facility operation, system compatibility, needed softwear development, and standardization.

In Section 3 of this report several types of data were identified. These include status data such as switch settings (on-off) or valve positions (open-closed) which are essentially binary; low frequency (<100 Hz) analog data such as vacuum pressures or temperatures in which the value of a slowly changing parameter is recorded; analog data of moderate frequency, from 100 Hz to a few kHz, typified by thermocouple and thermistor waveforms and much AGE data; higher frequency data (up to 20 MHz or so) associated with the pulse power source diagnosis in the stages prior to the diode; the output of the PRS and MBS has frequency components of up to 100 MHz; finally, at the highest frequency is SGEMP data with components up to several hundred MHz. This section discusses the availability of digitizing units for each of these frequency ranges.

In the low frequency range (dc to a few kHz), several of the IC manufacturers such as Analog Devices, National Semiconductor, Texas Instruments, and Motorola offer complete data multiplexing systems either on a chip or a card that are microcomputer compatible. These systems represent the lowest cost digitization schemes available and definitely should be considered as a possible solution to the low frequency digitization requirement.

In the frequency range up to a few megahertz, several commercial units are available. Some of these have been described in Reference 9.

A problem of more concern for SXTF instrumentation design is whether satisfactory transient data recorders (TDR) in the frequency range of ten to several hundred megahertz will be available at reasonable cost. As a minimum, one can envision a need for 75 to 100 channels with a digitizing capability of 100 MHz or more. If the need for time resolved diagnostics for each of the MBS modules should arise, then

a linear scaling of current diagnostic instrumentation practice would imply a requirement for $\sim 10^3$ of these units. At present there are only two commercially available transient digitizers with bandwidths of 100 MHz or more. The Biomation model 6500 is marginally useful, having a bandwidth of 100 MHz and costs $12K each. The Tektronix R7912 is satisfactory in regard to bandwidth but its price is ~$20K each. Thus, the cost of providing such capability on a very large scale would appear prohibitive. Unless the present cost of high frequency digitizers could be reduced by a factor of five or more, a key item for instrumentation development will be to acquire the ability to diagnose the MBS array using integral or peak detection techniques. However, the actual diagnostic scheme chosen will undoubtedly depend in part on the availability of low cost, high frequency transient digitizers. Therefore, monitoring the state of the art in this area is being carried out by IRT in its role as an instrumentation support staff.

The brief summary of available transient digitizers presented in Reference 9 makes it clear that there is no presently available commercial units which would permit the digitization of large numbers of high frequency data at a reasonable cost, say 1 to 2K per channel. Current costs are an order of magnitude higher.

In the course of our facility visits, however, we have found that there is a great deal of technology development going on in the area of high frequency transient data recording by the fusion, weapons diagnostics, and nuclear physics communities which also have a requirement for recording many channels of high frequency data (Ref 40). Our initial finding is that lower cost digitizers based on solid-state devices, primarily CCD arrays, may become available in the next few years which could be used to advantage in the SXTF facility. We will discuss these trends briefly.

4.4.2 Digitization Techniques

Several techniques have been considered for fast transient digitization, some of which have reached commercial realization. These are (1) parallel conversion, (2) scan conversion, and (3) time expansion. They will be discussed briefly.

The general principle of analog-to-digital conversion is shown in Figure 3. The analog signal is filtered before sampling to eliminate noise components which may contribute to spurious digitization. The amplitude of the signal during a time window narrow compared to the pulsewidth is sampled and held. This voltage is digitized through an ADC and stored in a digital memory. As a rule of thumb, digitizing a signal with significant amplitude changes in a time Δt requires a sampling rate of $\sim 5/\Delta t$.

For example, to digitize a 100 MHz signal, i.e., one with a rise time of ~3.5 nsec, requires a sampling rate of ~500 MHz. A principal problem in the digitization of high frequency signals is obtaining an ADC capable of operating at these rates with sufficient accuracy. A second problem is the requirement for storing digitized data at the same rate.

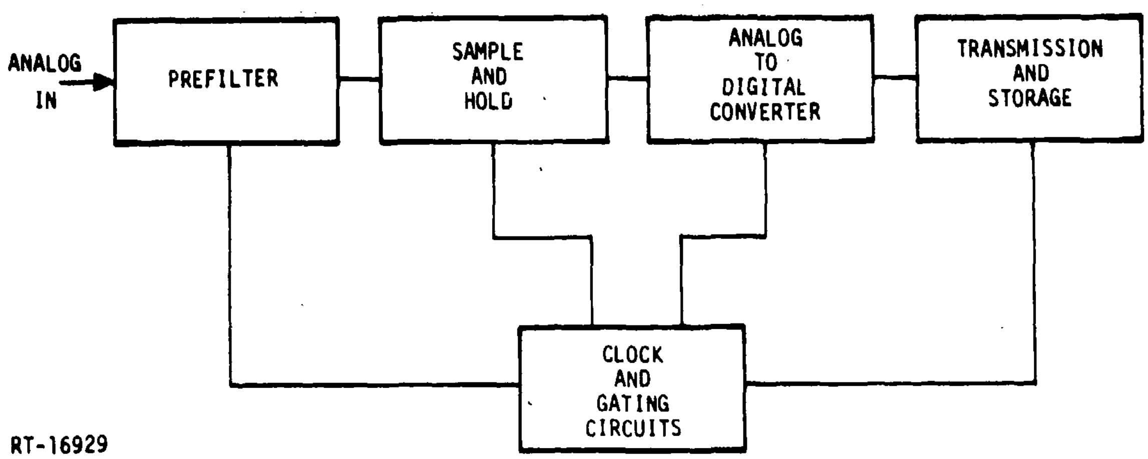

Figure 3. Classical analog-to-digital conversion system.

One means of eliminating the need for a high frequency ADC is the parallel converter technique. A typical circuit based on this process is shown in Figure 4. The ADC is replaced by a set of fast settling analog comparators whose sampling rate is clock controlled. If one wants an accuracy of 1 part in 2^n, one needs 2^{n-1} comparators. For a given analog input voltage all comparators below input level turn on while all comparators above it are off. The digitization process occurs in the switching time of a single comparator. The output of the comparators is presented in a form which requires encoding into binary form. There is no need for a sample-and-hold unit. The digitized data must still be stored at relatively high rates which requires a high speed memory. Prototype units of this type with a sampling rate of 200 MHz have been built. However, they are still relatively expensive (cost comparable to that of a Tektronix R7912) and a custom item. More representative of the state of the commercial art is a TRW device

which has a 30 MHz digitizing rate with 8-bit accuracy. It costs about $500 each in lots of one hundred. This price does not include the cost of input, output, and memory circuitry which doubles the cost per channel. On the other hand, the price for such units is expected to drop as more of them are manufactured. There is a good possibility that a relatively low-cost chip (a few hundred dollars each) with a moderately high signal bandwidth of ~20 MHz or so may be available. Such a unit would be useful for pulsed-power diagnoses, i.e., for monitoring pulse shapes in components before the diode converter in the PRS and MBS.

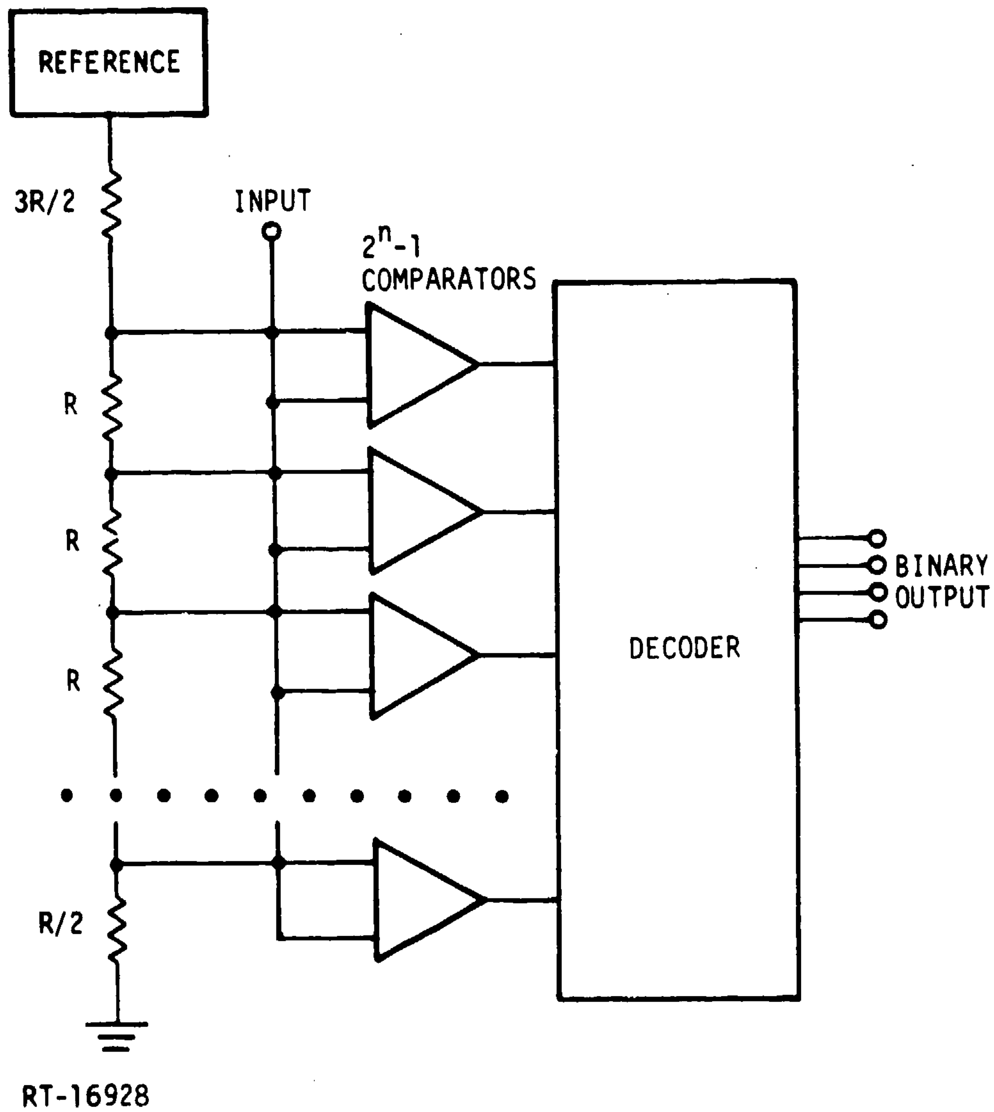

Figure 4. Parallel type A/D converter.

A second type of ADC is the scan converter. In such a device analog data is written onto a two-dimensional array which stores the signal as amplitude versus time. The array is subsequently read out at a slower rate and digitized. The prime example of a device of this type is the Tektronix R7912; however, a digitized scope photo would also be another example. The scan ADC currently offers the widest bandwidth capability as scopes are available which have single shot capabilities of up to 5 GHz and sensitivities of 1/2 volt per centimeter. Conversations with people involved in laser fusion and weapons diagnostics at LASL and L^3 indicate that work is going on to record the output of these fast scopes on a solid-state device such as a CCD array, either directly or by first intensifying the CRT light output in an image intensifier. While these units are satisfactory in regard to bandwidth and dynamic range, they are expensive (20K for a Tektronix R7912 and over 50K for the 5 GHz scope). It is not likely that their cost will be reduced even by an order of magnitude because of the cost of the electron gun system. In addition, operation of large numbers of these units (greater than 100) present problems because of size and power requirements. However, where the digitization of high frequency data is mandatory, i.e., SGEMP data, they are presently the device of choice, although costly.

The most promising technique for high frequency transient data digitization is the time expansion method. A block diagram for a TDR unit based on this scheme as taken from Reference 41 is shown in Figure 5. The essential aspect of devices built on this principle is that sampled analog data is stored in a set of peristaltic charge coupled device analog shift registers operating in a fast input/slow output mode. Use of CCD arrays permits the rapid storage of many individual voltage samples which may be read out and digitized at slower rates. Thus one eliminates the requirements both for a fast ADC and the need for correspondingly fast digital data storage. Individual CCD devices having a capability of storing sample data at a rate of 100 MHz or more are available. In practice, several parallel CCD registers are used with a multiphased clock in order to obtain the required sampling speed and number of sample channels. Each CCD register is gated by a different phase of the clock. At the end of the sampling period analog samples are read out of the CCD array at a lower rate, multiplexed, digitized, and stored. Because the conversion is relatively slow, one can employ standard and relatively inexpensive ADC's and solid-state IC memories.

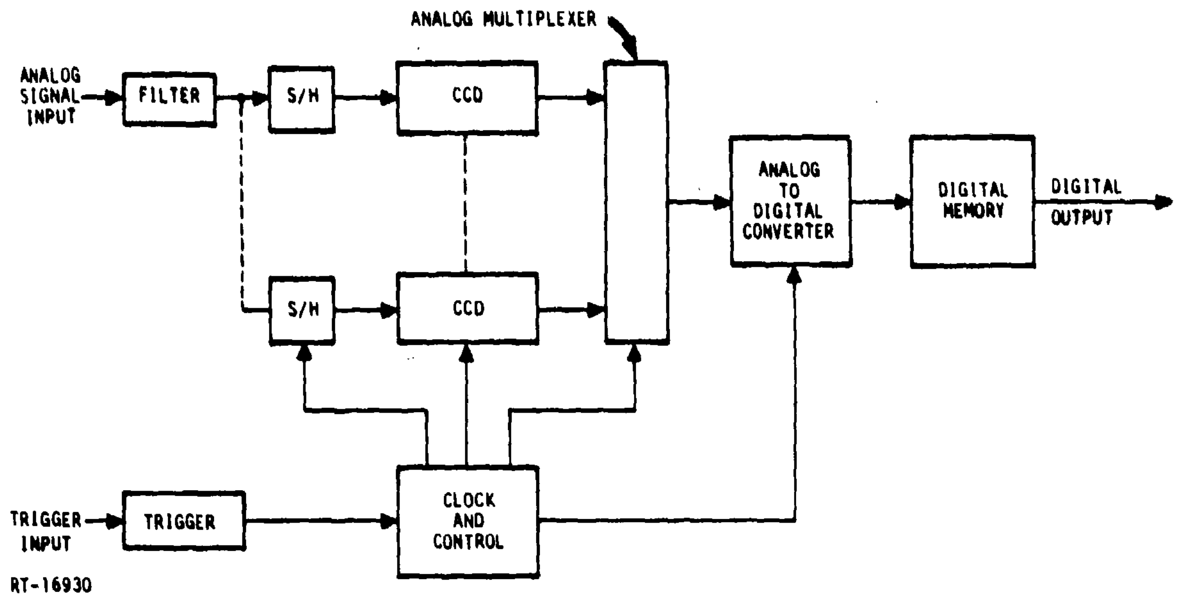

Figure 5. Fast in/slow out transient digitizer.

4.4.3 State of the Art

Typical of the state of the art in CCD-based transient recorders is that which has been built by Gard, Incorporated for Sandia Laboratories. This unit is built with eight parallel 128-bucket CCD chips driven by an eight-phase clock. It has a capability of sampling at rates of between 2.5 and 500 MHz giving the unit a bandwidth of approximately 100 MHz with a 6-bit accuracy and a 1024 sample capability. A similar unit has been built by L^3 which has a 200 MHz sampling rate and a 128 point sampling capability (Ref 42). Both units employ custom CCD's. The characteristics of the Gard digitizer make it adequate for pulsed power diagnostics. However, this is still a developmental device as is that of L^3 and relatively expensive ($10K for the Gard unit). In addition, work is progressing on digitizers which can operate at sampling rates of 1 GHz and up (Ref 43). The effective signal bandwidth of such a system is about 200 MHz. Such a unit would be marginally useful for recording SGEMP data. When developed, they should be significantly cheaper than the Tektronix R7912's.

The digitizing accuracy in these units is limited by the fixed pattern noise (relative difference in output of the individual CCD units). This can be minimized by prematching individual CCD's or by circuit compensation to balance the output of each of the individual CCD's. However, by careful circuit design it has been possible to build units with 2 percent resolution and 2 percent accuracy at a 500 MHz sampling rate. It

is to be noted that by choice of sampling technique both the Gard and L^3 units operate without sample-and-hold circuits.

An increase in the bandwidth capabilities of CCD-based digitizers will depend upon the development of CCD and control circuit technology. In principle the Gard unit is capable of operating at sampling rates up to 800 MHz corresponding to a bandwidth which approaches 150 MHz, while the individual L^3 CCD chips can sample at rates of 250 MHz. The speed of such a system depends on the 'ock rate. If the bandwidth of the L^3 unit can be increased by a factor of two then it would become an attractive replacement for the R7912's as it is likely to be a factor of two or so cheaper. It is not unlikely that multi-hundred megahertz bandwidth CCD-based transient digitizers will become available in the near future as this field of instrumentation is actively under development, not only by the National Laboratories but also by several commercial instrumentation manufacturers. It is to be expected that as CCD technology matures and the demand for CCD-based instrumentation increases, then the price of such units should decrease. The cost of any digitizer based on Government-funded technology will be lower to other government users if compared to that for commercial units because the front-end developmental costs will not be passed on. In addition it may be possible to build a dedicated transient digitizing unit with limited capabilities, i.e., with fixed period of digitization, a minimum number of points digitized, and single digitization rate, and limited amplitude capabilities at a significantly lower price than a more flexible unit.

In summary there is no transient digitization unit other than the 7912 which is currently available and in production which has the capability of digitizing data with bandwidths in excess of 100 MHz. However, the field is under active development such that the possibility of a CCD-based unit with satisfactory bandwidth and significantly lower cost may very well become available in time for its incorporation into the SXTF facility. Therefore it is recommended that a more careful survey be made of the state of transient digitization technology and that advances in the state of the art be monitored by the instrumentation staff. It may be advantageous for DNA to support the CCD waveform digitization field to ensure that a cheaper alternative to the R7912 becomes available.

5. SPACECRAFT CHARGING

5.1 PARTICLE ENVIRONMENT SIMULATION IN SXTF

In the past several years, the phenomenon spacecraft charging has been actively studied. Satellites placed in geosynchron orbits are subject to a natural particle radiation environment (as well as that associated with a nuclear detonation) that may cause spacecraft structures to become differentially charged. Such charging can generate sufficiently high potentials to cause dielectric breakdown leading to satellite damage, malfunction or, in extreme cases, possibly to failure. While the environment has not been determined in detail it is believed to have three components:

1. A low energy hydrogen ion plasma which during magnetic substorms can attain an effective temperature of 10 to 20 keV.

2. The natural trapped electron belt containing electrons with energies up to several MeV.

3. The artificial trapped electron belt created consequent to an exoatmospheric nuclear explosion. This component also is composed of relatively high energy fission electrons with energies comparable to or larger than that in (2). In addition, the peak flux may be several orders of magnitude higher.

In many respects, the stress placed on a satellite as a consequence of electrostatic discharges is similar to that created by other energizing radiation. External discharges can produce large currents and fields that can couple into cabling and the interior of the spacecraft if proper filtering and shielding are not supplied. The high energy component can penetrate the relatively thin skins of satellites, imbedding charge in cable dielectric, which may subsequently discharge, or directly in electronics, which can suffer dose rate or total dose degradation. The hardening techniques incorporated for SGEMP and TREE protection, namely electromagnetic and radiation shielding and filtering are also effective against the electromagnetic consequences of electrostatic discharges. On the other hand, the material degradation produced by the ESD has no direct SGEMP analogy. The two phenomena have been compared in References 44,45.

There are at least three reasons why a particle simulation of spacecraft charging phenomenon may be included in SXTF. First, since the phenomenon has been recognized as a possible threat to spacecraft survivability, current spacecraft expected to encounter such a charged particle environment are being hardened against its effects. It is likely that SAMSO will issue a Mil Standard for hardening military spacecraft against the consequences of ESD. In that case it would be desirable to develop a survivability proof test to validate ESD design practice in a manner similar to that for SGEMP. The SXTF would provide an ideal environment for carrying out spacecraft charging system survivability tests. The second reason is that some evidence exists that SGEMP response may be different in some respects for a charged satellite than for an uncharged satellite. For example, some experiments were performed as part of the SKYNET program in which the SKYNET qual model was precharged and then exposed to OWL-II photons. It appeared that some elements of the SGEMP response were enhanced (for exposure at the fluences attainable at OWL-II) when the spacecraft was precharged. Thus, a realistic simulation of the threat might include precharging. A third reason is that it may be desirable to test geosynchronous satellites for survivability against high energy particle environments. As pointed out above, the high energy component of the particle radiation field may cause volume charges or material degradation in spacecraft cabling and electronics.

Therefore, the addition of a charged particle environment simulation capability to the SXTF may be very desirable. Such a capability would presumably consist of a number of electron and ion guns and a solar simulator arranged to irradiate the test satellite with particles of flux and energy spectrum representative of environments likely to be encountered during space missions. The main purpose for providing a charge particle environment in SXTF is to enable performance of photon tests on satellites that have been precharged in a realistic manner. The facility could also, of course, be used to test for survivability against spacecraft charging phenomena alone with the qual model spacecraft.

Several issues arise in a consideration of the requirements for such a capability in SXTF:

1. Specific particle environment characteristics to be simulated

2. Availability of appropriate particle sources

3. Compatibility with primary functions of SXTF and impact on the facility

4. Cost options

In the following, these issues are addressed in a general manner for the purpose of establishing a basis for future detailed investigations, which would lead to hardware design and development.

5.2 SATELLITE ENVIRONMENT

5.2.1 Natural

The charged particle environment to which a spacecraft is subjected during a mission is not only complex, but also highly variable with time and location. To the present time, most investigations of spacecraft charging phenomena have been concerned with the effects of low-energy substorm plasma electrons. A joint NASA/SAMSO program has been established to investigate such effects (Ref 46). Differential charging and subsequent breakdown have been attributed to these electrons, of energies 2 to 25 keV. Effects of such electrons have been simulated in laboratory materials studies with monoenergetic electron beams operated at current levels representative of fluxes observed on the geosynchronous satellites ATS-5 and ATS-6. Under DNA sponsorship, one system test on the SKYNET qual model has also been conducted in a vacuum tank at Physics International.

Geomagnetic substorms occur approximately 30 percent of the time, with rapid variations in electron energy spectra and flux levels. From the (sketchy) data available, it appears that the natural substorm environment can be simulated by irradiation of a satellite with up to 10 nA/cm^2 of electrons having a spectrum of energies from 2 to 30 keV. The necessity for including a simultaneous simulation of the rest of the environment (protons, UV) is not clear at the present time, although UV radiation is known to be of importance. The question of the best actual shape of the energy spectrum also deserves detailed study. It is not presently clear whether or not a monoenergetic beam of appropriate energy would provide a valid simulation. The flux figure of 10 nA/cm^2 represents a conservative estimate of the maximum expected in the natural environment, based upon presently available data.

In addition to the low-energy substorm environment, satellites are subjected to a low (up to $\sim 5 \times 10^{-12}$ A/cm^2) flux of high energy (0.05 to 4 MeV) electrons. While not investigated to any detail in SCATHA, ionization effects produced by high energy electrons have been considered by agencies such as DNA and NASA. High energy electrons have the ability to penetrate into the volume of dielectrics and even into interior components of the spacecraft. Volume charges can create a different class of

problems and required remedies from that considered previously in spacecraft charging investigations. Given present knowledge, it would thus appear advisable to include a simulation capabiltiy for the high energy environment in SXTF, if such a capability is practical.

Although the positive ion fluxes encountered in the spacecraft environment are normally about a factor of 50 or so less than electron fluxes, ions may contribute to spacecraft charging phenomena. Both H^+ and O^+ have been observed at geosynchronous altitudes, often with comparable intensities. Since secondary electron emission coefficients for positive ions are rather large, especially for ion energies above a few keV, the ion current to the satellite is, in effect, magnified. If the satellite is negatively charged, the ions will be accelerated as they approach the satellite, so that even ions with low initial energy can impact with sufficient energy for high secondary coefficients. (Present data suggests that the average ion energy is about twice the average electron energy.) Penetration of ions into spacecraft surfaces is less than for electrons, so that dipole layers can be formed in insulators, possibly contributing to discharges. In fact, one mechanism postulates that the major contributor to production of replacement currents is the collapse of a surface dipole layer and subsequent emission of particles away from the spacecraft surface (Refs 47,48). In addition, the ion flux is often highly anisotropic, allowing the possibility of differential charging (Ref 49). Since there is increasing evidence of anisotropies in the distribution of electron fluxes as well as ion fluxes, especially along magnetic field lines, a simulation facility should possibly have the capability of directing more intense flux along certain directions than others.

A strong role is undoubtedly played in spacecraft charging phenomena by incident UV radiation. Surfaces exposed to UV will tend to remain at ambient plasma potential, whereas shadowed surfaces may be charged to high potentials by particle bombardment. For proper simulation of the effects of the particle environment in SXTF, simultaneous illumuniation of the satellite with a solar simulator may be necessary.

There is little experimental data available either from satellite experiments or from ground testing on the effect of a distributed electron spectrum or of ions in producing discharges. Hopefully, more information will be available on what constitutes an adequate simulation of the natural component of space environment charging at the end of the SCATHA program in mid-1981.

5.2.2 Artificial

High-altitude nuclear detonations result in enhanced electron flux at geosynchronous altitudes. Some work (e.g., Ref 50) has indicated that the low-energy plasma electron flux at geosynchronous orbit may reach 2×10^{-6} A/cm^2 for times on the order of seconds following a nuclear burst. In addition, the mean energy and flux of the high energy electrons are enhanced. The resulting spacecraft charging can be very severe, involving potentials of tens of kilovolts. Above-normal flux levels may persist for long times.

The charged particle environment that presently appears to be of importance to spacecraft charging is summarized in Table 1.

Table 1. Charged Particle Space Environment of Importance to Spacecraft Charging

Particles	Energy	Maximum Incident Flux (A/cm^2)
Natural low-energy plasma substorm electrons	2 - 30 keV	10^{-8}
Natural high-energy electrons	0.05 - 4 MeV	5×10^{-12}
Natural positive ions	2 - 50 keV	2×10^{-10}
Artifical low-energy plasma electrons	2 - 30 keV	2×10^{-6}
Artificial low-energy positive ions	2 - 50 keV	4×10^{-8}
Artificial high-energy electrons	0.1 - 5 MeV	5×10^{-10}

5.3 PARTICLE SOURCES

In order to provide a natural particle environment simulation capability in SXTF, sources for some or all of the following are required:

Electrons, 2 to 30 keV, $> 10^{-8}$ A/cm^2

Positive ions (H^+, O^+), 2 to 50 keV, $> 2 \times 10^{-10}$ A/cm^2

Electrons, 0.05 to 4 MeV, $> 5 \times 10^{-12}$ A/cm^2

If simulation is desired for the environment created by a nuclear burst, then the total current figures for electrons must be multiplied by a factor of approximately two hundred. Reasonably uniform flux over divergence angles of up to 20° may be required for sources placed near the wall of the SXTF vacuum tank. Some candidate sources are discussed below.

5.3.1 Conventional Hot-Cathode Sources

Simple, single-lens electron guns can be designed that will produce 2 to 30 keV monoenergetic beams of the proper divergence for a particular application. An example is provided by the electron source constructed for the Phase V SKYNET photon tests (November 1977). That device (Ref 51) produced electrons of up to 25 keV energy with currents up to 10 nA/cm^2 on target. A beam uniformity of ±20 percent over a 2.25 m^2 target area was achieved with a source to target distance of 2 m, and the divergence was relatively independent of beam energy. A source of this type can be designed for any fixed divergence and can produce any desired effective energy spectrum by use of programmed voltage sweep capabilities. (Such a source is being incorporated in the NASA Lewis Spacecraft Charging Test Facility. That electron gun will be rastered in energy at a rate of about 1 Hz between 0.5 and 20 keV (Ref 52).) A cluster of discrete-energy sources is another possibility for spectrum simulation. If the electron sources are required to have variable divergence (e.g., in order to accommodate test satellites of significantly differing sizes), then more than one lens may be required, or a masking scheme can be devised.

It is possible that hot-cathode sources could be used for simulation of spacecraft environment up to energies of 200 to 300 keV, or more. Appropriate DC power supplies are readily obtainable and are not expensive, but much care would have to be exercised in the design and construction of the electron gun insulation. The tank vacuum would probably have to be well below 10^{-5} torr during operation of the sources at such high

potentials. (The presence of cold walls to maintain the spacecraft thermal balance should help the achievement of this pressure.) Again, sweeping of the accelerating voltage for spectrum simulation would be possible. Use of resonant AC transformers for this purpose might be advantageous. An alternative scheme for generating a spectrum would employ a foil scatterer, although this method requires a factor of 100 higher initial current from the source.

An electron source designed for low energy (< 50 keV) can be very small and compact. However, as the design energy increases, so much the physical size of the device and of the power supplies. This must be kept in mind for situations where there are physical size restrictions or where flexibility in placement is desired.

An extensive review of electron sources and their availability and costs is to be found in Reference 53.

5.3.2 Multipactor Electron Sources

The multipactor source (Ref 54) has attractive features for application to spacecraft charging simulation. This device has no hot cathode--it consists of two metal plates with an rf voltage applied between them. Stray initial electrons are accelerated to a plate where they create secondary electrons which are in turn accelerated to the other plate by the reverse field, and so on. Charge multiplication by multipactoring occurs in various modes according to relationships between the rf frequency, the rf voltage, and the electrode spacing.

Such a discharge can be used as an electron source by installing a perforated plate as one multipactor electrode, a grid for electron extraction and current control, and a grid for acceleration to the desired energy (Figure 6). The multipactor electrodes are probably most conveniently shaped with spherical curvature in order to produce appropriate beam divergences. The divergence can be easily modified in situ by mechanically masking the perforated electrode. It should be noted that the beam pattern need not be axially symmetric at the target position; custom patterns can be readily be created by appropriate masks. Beam current densities of 5 $\mu A/cm^2$ have been achieved at SRI with a very simple multipactor source and with no attempts at optimization for maximum current.

For satellite charging simulation, the multipactor source offers advantages of simplicity, contamination resistance, high stability, no light output, low maintenance, and ease of irradiation coverage modification. The device should be useful for the same

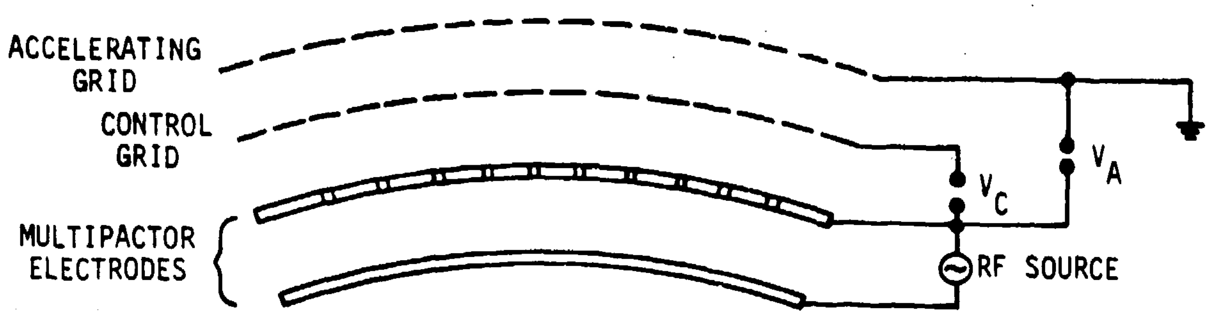

Figure 6. Schematic diagram of multipactor source. The current is controlled by potential V_C and V_A is the accelerating potential.

electron energy range as hot cathode sources ($\lesssim$250 keV). The cost per unit should be comparable to that of the simplest type of hot-cathode source. Energy spectrum simulation can be achieved by programmed accelerating and control grid bias voltage sweeps. Alternatively, it may be possible to produce a broad energy spectrum by employing rf modulation techniques.

5.3.3 Positive Ion Sources

Many types of positive ion sources are available for production of total currents in the range of tens of microamperes to tens of milliamperes. Fairly simple electron bombardment or rf discharge sources are suitable for currents up to a few hundred μA. Higher currents require plasma sources, such as the duoplasmatron. Spectrum simulation could, in principle, be accomplished by voltage sweeping. Ion sources are necessarily more complex than electron sources, since a gas feed system and usually a water cooling system are required. In addition, some types require a magnet with associated power supply.

With introduction of gas and reversal of extraction potentials, the multipactor electron source can be used as a positive ion source. The characteristics of such a device are not presently known, but the current density attainable should be sufficient for applications to spacecraft environment simulation. An interesting possibility would be that of operating a multipactor source with AC extraction potentials, thereby providing electron and positive ion beams from the same source. A considerable savings in cost and complexity would result if this could be done for SXTF.

If the test satellite charges to any degree under electron bombardment, then a certain ion current to the satellite will result from the volume production of ions from residual gas by the beam electrons. The magnitude of this current will depend upon the background gas pressures.

5.3.4 High-Energy Electron Sources

Production of electrons with energies of 0.5 to 5 MeV requires what is usually termed an accelerator. The most common and readily available types for this energy range are van de Graaffs or dynamitrons. The characteristics, availability, and cost of such accelerators have been reviewed by Shea (Ref 53), so that only a brief comment on the subject will be presented here.

Accelerators for energies up to 5 MeV are large and expensive. Furthermore, extensive radiation shielding would be required at the higher energies. There seems to be little doubt that such accelerators would require permanent installation. Full target coverage could be provided with a raster system (available for about $15K with six-week delivery).

5.4 CONSIDERATIONS FOR SXTF

5.4.1 Physical and Electrical

If it is decided from laboratory testing that the worst case simulation of the space particle environments in SXTF requires reasonably uniform irradiation of a test satellite with particle beams as an approximation to the isotropic flux of the space environment then four to six sources will probably be needed for each species of particle (up to ten if three-axis stabilized satellites with deployed solar panels are to be tested). The sources are expected to be mounted near the vacuum wall, so that they must be compatible with EM dampers, backscatter grids, cold walls, etc. In particular, the sources would have to be placed so that particles are not significantly scattered before reaching the spacecraft. It would be advantageous for the sources to be movable in order to allow flexibility in accommodating various satellite and instrumentation configurations and changes in irradiation scheme. This would almost certainly not be possible for high energy electron sources which, because of their sizes, would probably have to be mounted outside the vacuum tank. Small sources (e.g., 2 to 30 keV electron guns) could be attached to the vacuum tank wall with magnetic clamps.

Regardless of the types of sources used, a certain fraction of the particle beam current will miss the satellite and will thus impinge upon the tank walls, grids, fiber optic cables, etc. (q.v. Section 4.3). Sections of insulating surfaces (e.g., glyptol, optical fibers) may charge to high potentials under such bombardment, leading to discharge problems within the tank. Some types of sources may be worse than others in this respect, since a fairly large beam divergence may be necessary in order to obtain sufficient uniformity over the target. This problem can be minimized, but probably not eliminated, by properly collimating the source in a manner similar to that being considered for the photon sources. On the other hand, a grid network included to catch stray photoelectrons would also be affected by the low energy electrons (but not the high energy component).

Care must be taken in the design of particle sources and their associated systems to ensure that no interference is caused to other SXTF systems or instrumentation. Besides the stray electron effects mentioned above, sources can generate RFI that can affect other systems. Substantial x-ray production can be expected from the use of high-energy electron sources. The fluence would have to be low enough not to interfere with the photon test dosimetry.

Since the SXTF vacuum tank is rather large and the electron beam path lengths would be long, residual magnetic field levels must be considered. If the full earth's field were present in the tank, then targeting the low-energy electrons could be difficult because of their small ($\sim$10 m) gyroradius. The steel tank should provide enough shielding, however, to reduce the residual field to acceptable levels.

If a particle environment simulation system is installed in SXTF, then provision must be made for monitoring the system operation. Instrumentation must be developed, for example, to measure the particle flux incident on the spacecraft, the potential of the spacecraft, etc. These are not off-the-shelf items and may require some development.

5.4.2 Cost

It is apparent that the cost of a particle environment simulation system for SXTF would depend very strongly upon type and the energy range of particles to be used. Simulation of the natural low-energy electron environment would not be expensive; perhaps $50 to 100K for eight sources with associated electronics and power supplies.

Ion sources would cost somewhat more. Costs rise rapidly if higher energies and/or currents are considered--a factor of ten or so for full simulation to ~300 keV. Availability and developmental lead time must be assessed.

High-energy electron sources (to 4 or 5 MeV) would represent a high cost, as well as generating major facility impact problems. Basic costs for the sources alone are several hundred thousand dollars per unit, but design and installation costs (shielding, support structures, etc.) would be substantial. It is clear that a careful cost-benefit analysis should be performed if high-energy sources are to be considered for SXTF.

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Air Force Weapons Lab
Air Force Systems Command
ATTN: SUL
ATTN: NT
ATTN: NTSW, Col Bloemker
2 cy ATTN: NTYC

Air University Lib
Department of the Air Force
ATTN: AUL/LSE

Ballistic Missile Ofc
Air Force Systems Command
ATTN: SYDT
ATTN: ENMG
ATTN: ENSN

Deputy Chief of Staff
Rsch, Development, & Acq
Department of the Air Force
ATTN: AFRDQI

Headquarters Space Div
Air Force Systems Command
ATTN: YKD

Headquarters Space Div
Air Force Systems Command
ATTN: YNV

Rome Air Development Center
Air Force Systems Command
ATTN: ESR, E. Burke

Strategic Air Cmd
Department of the Air Force
ATTN: XPFS
ATTN: NRI, STINFO Lib

OTHER GOVERNMENT AGENCIES

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National Oceanic & Atmospheric Admin
ATTN: F. Fehsenfeld

NASA
Lewis Rsch Ctr
ATTN: Lib
ATTN: N. Stevens
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ATTN: [illegible] Dept, Lib

Los Alamos [illegible] Lab
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Sandia Labs
Livermore Lab
ATTN: T. D[illegible]

Sandia Nat Lab
ATTN: 3141

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ATTN: A. Schiff

EG&G Wash Analytical Svcs Ctr, Inc
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Hughes Aircraft Co
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ATTN: Class Lib

IRT Corp
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ATTN: B. Williams
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4 cy ATTN: J. Wilkenfeld
4 cy ATTN: R. Galloway
4 cy ATTN: A. Kalma
4 cy ATTN: J. Dowell
4 cy ATTN: W. Hardwick

JAYCOR
ATTN: Lib
ATTN: E. Wenaas

JAYCOR
ATTN: R. Sullivan

JAYCOR
ATTN: R. Poll

Kaman Sciences Corp
ATTN: Lib
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ATTN: Dept 85-85

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ATTN: R. Kloster

McDonnell Douglas Corp
ATTN: S. Schneider

Mission Research Corp
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Mission Research Corp
ATTN: B. Goplen

Mission Research Corp-San Diego
ATTN: Lib
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Mission Research Corp
ATTN: W. Ware

Pacific-Sierra Research Corp
ATTN: L. Schlessinger
ATTN: H. Brode

R & D Associates
ATTN: Tech Info Ctr
ATTN: S. Siegel
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Rockwell International Corp
ATTN: Lib

Science Applications, Inc
ATTN: W. Chadsey

Science Applications, Inc
ATTN: D. Woodward
ATTN: K. Sites

Spire Corp
ATTN: R. Little

SRI International
ATTN: Lib

Systems, Science & Software, Inc
ATTN: A. Wilson
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ATTN: I. Ford

TRW Defense & Space Sys Grp
ATTN: D. Clement
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